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TIME-SERIES STUDY OF SANDING IN VENTURA HARBOR, CALIFORNIA

Mario Edmundo Carneiro Vieira

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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TIME-SERIES STUDY OF SANDING
IN VENTURA HARBOR, CALIFORNIA

by

Mario Edmundo Carneiro Vieira

March 1974

Thesis Advisor: W.C. Thompson

Prepared for:
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in Ventura Harbor, California
by

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An analysis of sand accumulation was carried out in the entrance channel of Ventura Harbor based on 44 quasi-monthly sounding surveys made over the four-year period from January 1965 to January 1969. The accumulation was found to follow a marked seasonal pattern of little or no deposition in summer (May to October) and maximum deposition in winter (between November and March). The sand mass, which assumed a characteristic slope

(20. ABSTRACT continued)

depending upon wave exposure, accumulated in greatest amount just inside the seaward end of the North Jetty around which the sand is supplied by downcoast littoral drift. The amount of sand trapped by the harbor averaged 137,000 cubic yards per year, or one-third of the estimated net annual littoral drift along this coastal sector. Waves are the principal vehicle for sand transport into the inlet as indicated by the close correlation found between the seasonal rates of accumulation and the seasonal wave regime, and from dynamical consideration of the tidal current through the entrance channel.

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An analysis of sand accumulation was carried out in the entrance channel of Ventura Harbor based on 44 quasi-monthly sounding surveys made over the four-year period from January 1965 to January 1969. The accumulation was found to follow a marked seasonal pattern of little or no deposition in summer (May to October) and maximum deposition in winter (between November and March). The sand mass, which assumed a characteristic slope depending upon wave exposure, accumulated in greatest amount just inside the seaward end of the North Jetty around which the sand is supplied by downcoast littoral drift. The amount of sand trapped by the harbor averaged 137,000 cubic yards per year, or one-third of the estimated net annual littoral drift along this coastal sector. Waves are the principal vehicle for sand transport into the inlet as indicated by the close correlation found between the seasonal rates of accumulation and the seasonal wave regime, and from dynamical consideration of the tidal current through the entrance channel.

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I wish to express my gratitude to Dr. Warren C. Thompson for his precious, dedicated and patient advice during the preparation of this thesis. It is of interest to note that the Oceanographic Services, Inc. (Phase II) report (1965), from which significant background information was obtained, was prepared by Professor Thompson.

I also want to thank the Ventura Port District authorities, in the person of the General Manager Mr. K. C. Klinger, who made the original sounding records available, provided background information on the harbor and was such a gracious host during a visit to the harbor. To Mr. Charles Holt of the Los Angeles District Corps of Engineers go my thanks for making the files of sounding surveys available for this study and providing pertinent reports on loan.

To my wife Jane I extend my appreciation for the encouragement and loving support which made it all so much easier.

I. INTRODUCTION

A. THE MARINA

Ventura Marina is a man-made harbor on the coast of California, 65 miles to the northwest of the city of Los Angeles. The harbor consists of three interior basins and a network of keys. The entrance channel, which is the specific concern of this thesis, is confined by two rubble-mound jetties and has a spending beach on the south side, designed to absorb the energy of the incoming waves (Figures 1 and 2).

B. BACKGROUND

1. Physiography of the Area

Ventura Harbor lies on the flat coast of an embayment contained between the Ventura River delta to the north and the Santa Clara River delta to the south. The Santa Clara river empties about one half mile south of the marina entrance (Figure 2).

The low lying plain on which the harbor was excavated extends about one half mile inland to the base of a 75-foot cliff. This is an old sea cliff, seaward from which the plain has been built by littoral processes in historic time.

This coastal area has been very dynamic. The Santa Clara River in some years transports great quantities of sediment and builds out its delta. This acts basically

Figure 1: Ventura Marina (U.S. Navy Photo)

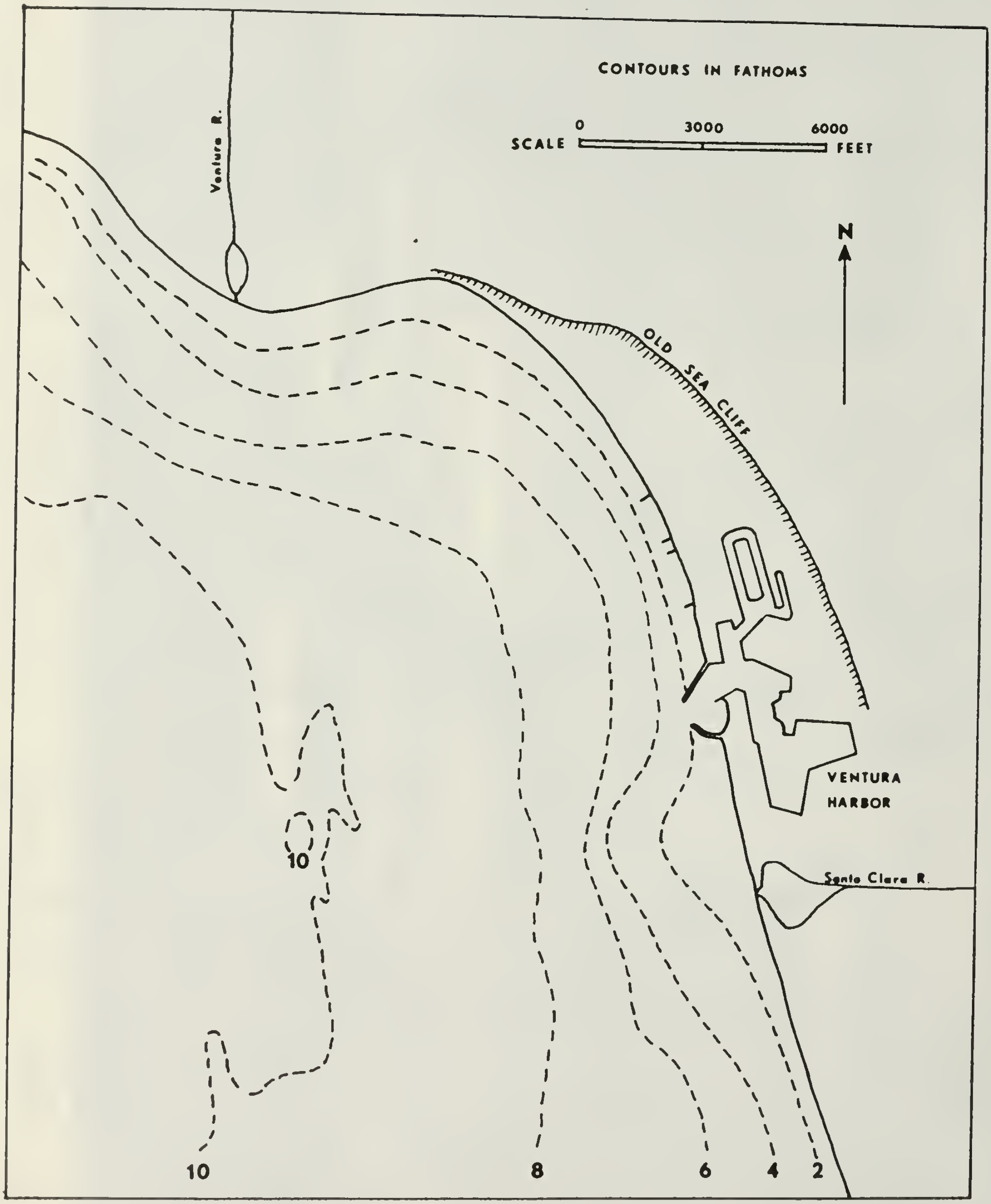

Figure 2: Ventura Marina and Vicinity

as a groin which disturbs the southward flowing littoral drift, resulting in a generally prograding shoreline in the embayment. The seaward advance of this shore between the river discharges has been, however, counteracted by erosion during years of little runoff (Oceanographic Services, Inc., (Phase II), 1965).

2. <u>Wave Exposure</u>

Ventura Harbor is subject to a reduced exposure to swell from the open ocean since it is sheltered by the coast and by the Santa Barbara Channel Islands (Figure 3). The latter act as a filter, allowing only narrow directional bands of approach from the west, southwest, and south. The fetch in these directions is unlimited and permits the generation of large wind waves. Fetches in nearly all other directions outside of these three bands are under 20 miles and prohibit the growth of large seas.

Refraction diagrams (Corps of Engineers, 1970) show that the marina is situated in an area of strong convergence for a wide spectrum of westerly waves, which are the dominant waves at the marina opening.

3. <u>Littoral Drift</u>

From statistical wave studies (Corps of Engineers, 1970), it was ascertained that the most important waves affecting Ventura Marina throughout the year, in terms of energy and frequency of occurrence, predominate from the sector 250° to 280°. This results, as summarized in the

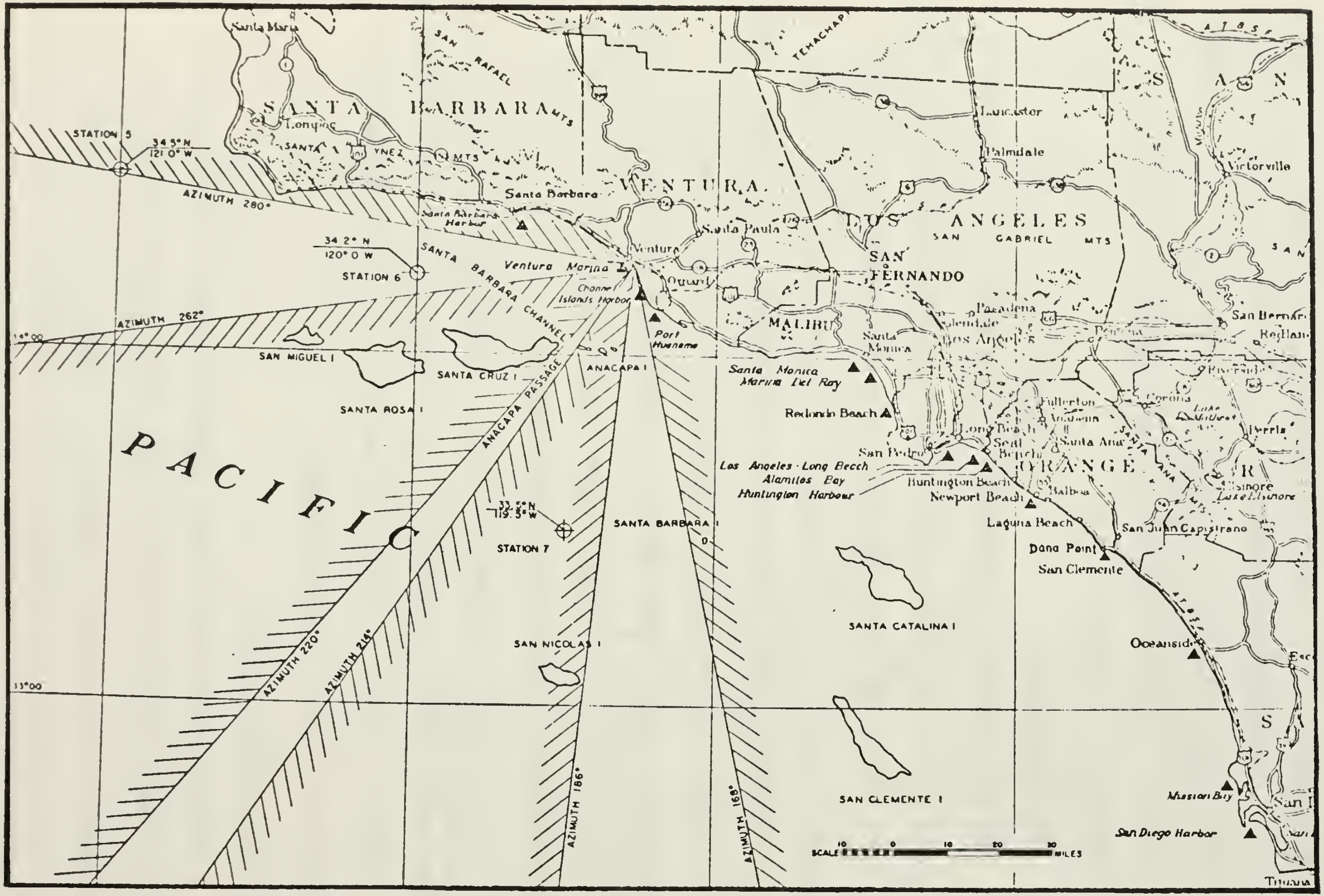

Figure 3: Wave Exposure of Ventura Marine Entrance
(from Corps of Engineers, 1970)

Oceanographic Services, Inc., report (Phase II) of 1965, in a net annual downcoast (Southerly) littoral drift in this area. The rate of sediment transport has been estimated at 400,000 cubic yards per year in this region of the coast (Department of Water Resources, 1969).

C. HISTORY

Ventura Marina, designed by John A. Blume and Associates of San Francisco, was excavated out of sandy soil and opened to use in March 1963 after completion of the jetties and dredging of the entrance channel. The keys were excavated later and opened in January 1965.

Since its inauguration the harbor has been plagued with two hazardous conditions; namely, shoaling and resultant severe wave breaking in the entrance channel. This situation prompted a series of dredgings, to a design depth of -20 ft Mean Lower Low Water (MLLW), which have been carried out once a year since 1964 by the Shellmaker Company. The spoil was placed on the beach south of the South Jetty.

In January and February of 1969, heavy flooding of the Santa Clara River breached the north bank and diverted the river partially through Ventura harbor, causing great damage in the marina and surrounding area. The rehabilitation program that followed provided for dredging of the harbor basins and entrance channel.

An intensive review of the shoaling and hazardous wave conditions of Ventura Marina was undertaken by Oceanographic Services, Inc., which, at the end of a two-stage study

recommended in 1965 the construction of an offshore breakwater. This was designed to shelter the harbor entrance from the dominant westerly waves, creating at the same time an area of quiet water in its lee on the upcoast side of the North Jetty which would act as a sand trap for the sediment moving downcoast. Following authorization by the Congress for modification of the harbor, the U. S. Army Corps of Engineers published in 1970 the design memorandum with the plans and specifications for the construction of the offshore breakwater and the surveys and studies made in connection with that project (Corps of Engineers, 1970). The breakwater was completed in 1972.

II. OBJECTIVES

With the purpose of monitoring the shoaling situation in the entrance to the marina, the Ventura Port District has carried out since 1964 a program of quasi-monthly soundings of the inlet. These sounding surveys constitute an excellent time series of the shoaling history. A series of these surveys was selected for study in this thesis, starting in January 1965 just after the keys were opened and the interior configuration of the harbor was completed, and ending in January 1969 just prior to the heavy floods which ravaged the marina. The design of the harbor remained static during this four-year period.

The objectives of this thesis are: (1) the determination of the space-time pattern of sand accumulation in the entrance, or inlet, of Ventura Marina over the period from January 1965 to January 1969, between the opening of the keys and the 1969 floods; and (2) the explanation for the pattern.

III. THE SOUNDING DATA

The soundings of the harbor entrance, made under the direction of the Harbormaster of the Ventura Port District, constitute the basic data for this study. The soundings cover the outer part of the main channel connecting the inner harbor with the ocean, which is the area of serious shoaling and wave conditions. No soundings were made in the area between the main channel and the spending beach. As will be discussed, this area appears to behave independently of the main channel.

The surveys were carried out at quasi-monthly intervals using a small boat in good sea conditions at any stage of the tide. The soundings were taken using a lead line in earlier work and a fathometer with visual indicator later. The precision of these uncorrected soundings is estimated to be $\pm$ 0.25 ft.

The survey procedure involved the use of permanently fixed range marks on the North Jetty at 100 ft intervals. A marked tack-line was stretched taut from the boat perpendicularly to a man on the jetty at every range mark. The marks on this tack-line were 50 and 100 feet apart and they determined the location of the sounding stations. Where this method was not viable, namely outside the entrance, bearings were taken and distances estimated. The pattern of the soundings is shown in the charts in the Appendix.

The soundings from each survey were corrected by the Ventura Port District for the transducer depth when appropriate and for the tide stage at 15-minute intervals relative to a floating gauge in the harbor, and were plotted in chart form with reference to Mean Lower Low Water. These charts were used in all of the work in this thesis related to bathymetry.

The precision obtained by these corrected soundings was considered insufficient for the computerized volumetric calculations presented in this thesis. For this purpose the original sounding data were reduced to MLLW using tide corrections to 0.1 ft derived from the tide tables (National Ocean Survey). The precision of these corrected soundings is estimated to be $\pm$ 0.3 ft.

The dates of the 44 sounding surveys utilized and of the four annual entrance dredgings are listed in Table I. Copies of the working charts, drawn by the Ventura Port District and contoured by the writer at 2 ft intervals, are presented in chronological order in the Appendix.

TABLE I

SURVEY AND DREDGING DATES

Sounding series

28 January 1965
11 February 1965
12 April 1965

Entrance dredged 24 May - 9 June 1965

Sounding series

10 June 1965	5 January 1966
9 July 1965	11 February 1966
11 August 1965	4 March 1966
10 September 1965	24 March 1966
13 October 1965	15 April 1966
12 November 1965	
3 December 1965	

Entrance dredged 2 - 14 May 1966

Sounding series

17 May 1966	19 January 1967
6 June 1966	8 February 1967
18 July 1966	3 March 1967
19 August 1966	26 April 1967
21 September 1966	9 May 1967
21 October 1966	
23 November 1966	
28 December 1966	

Entrance dredged 19 May - 6 June 1967

Sounding series

2 June 1967	31 January 1968
8 September 1967	11 March 1968
17 October 1967	20 March 1968
29 November 1967	11 April 1968
27 December 1967	9 May 1968

Entrance dredged 23 May - 8 June 1968

Sounding series

31 July 1968	16 January 1969
4 September 1968	
9 October 1968	
28 November 1968	
18 December 1968	

IV. ANALYSIS OF THE FILLING

The time-space changes in shoaling of the harbor entrance were determined through analysis of sand volume changes, migration and change in depth of the channel axis, and movement of selected contours from one survey to the next over the four-year period.

In order to evaluate the change in volume of the sand fill between surveys, a computer program was designed. For this purpose the area of the inlet covered by the Ventura Port District soundings was fitted with a grid of unit mesh 100 feet by 50 feet, as depicted in Figure 4. The volume change between successive surveys for each unit area was obtained in the following way; the differences in the four soundings at the corners of the unit were calculated between surveys, these differences were averaged, and were multiplied by the area of the unit to yield the volume difference. The summation of all the units gave the volume difference for the whole inlet between the two surveys, whereas the addition of the units in transverse or longitudinal sections represented the respective sectional volume differences between surveys. It is appropriate to note at this point that Transverse Sections 1 and 2 are open ended on both extremities, and that Sections 3 through 7 are open ended opposite the spending beach.

In some of the figures to be presented, the reader will note occasional negative values of volume change between

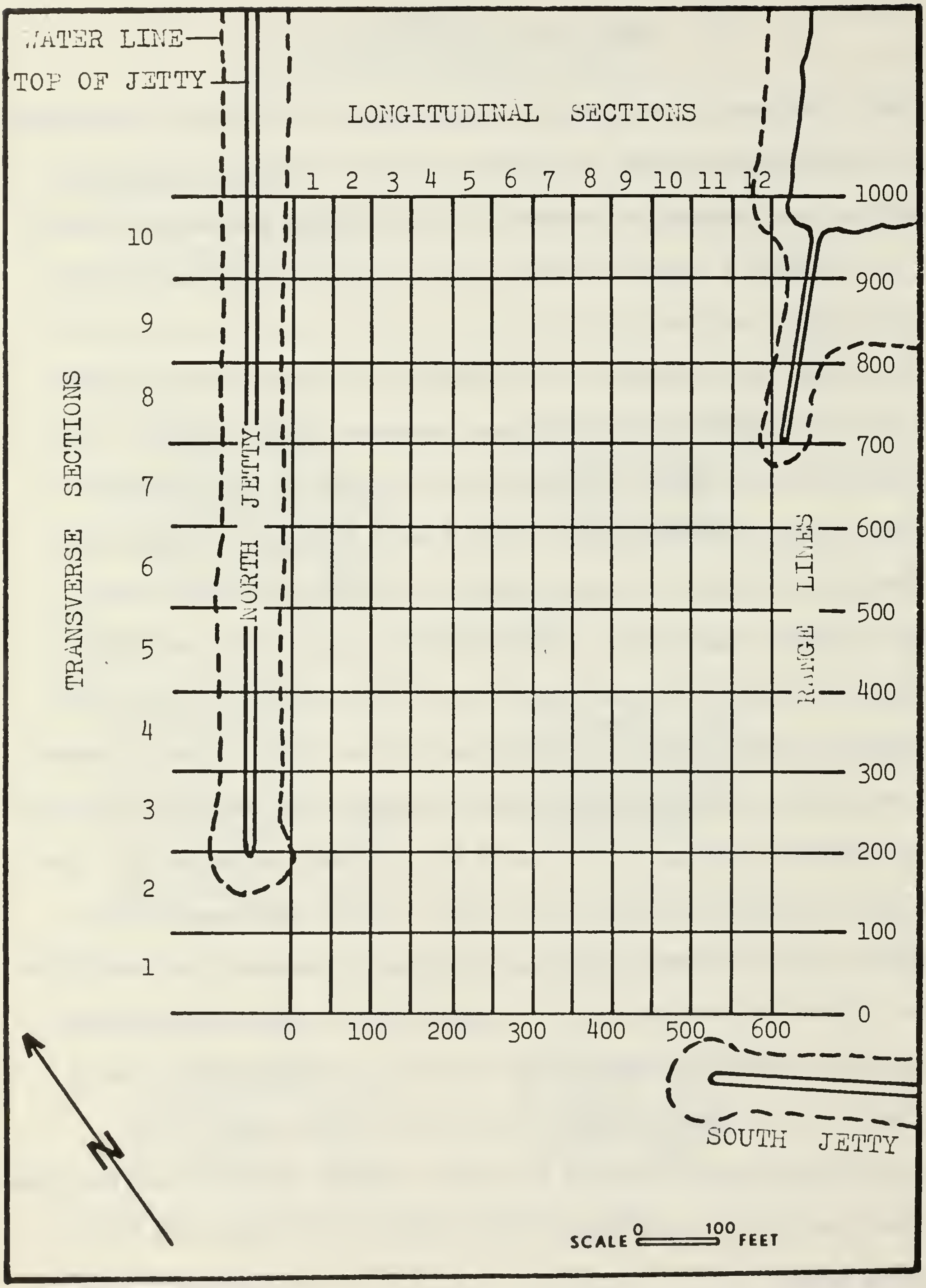

Figure 4: Ventura Marina Inlet Sounding Grid and Sections

surveys of generally small magnitude. These are believed to be due principally to the precision of the soundings and not to the removal of sand. A precision in the soundings of ± 0.3 feet represents a precision on the order of ± 56 cubic yards for a unit area and ± 6,700 cubic yards for the whole inlet. The fact that the area studied is open ended opposite the spending beach may account for some of the negative volume changes, presumably due to some sand exchange between the inlet and the beach.

A. SEASONAL DEPENDENCY

A marked seasonal pattern was found to occur for the sand fill in the whole inlet. This pattern is apparent in Figure 5, which is a graph of the sand volume changes for the inlet between successive surveys during the four years encompassed by this study. Aside from the small apparent volume losses attributed principally to precision, it is clear that after the dredging in late spring, the sand accumulates at a very slow rate during the summer. The rate increases rapidly between September and November, attains a maximum value between about November and March, and then abruptly decreases. The greatest rate of accumulation between surveys was 8,000 cubic yards in August-September 1966.

This seasonal pattern is further illustrated in Figure 6 which shows the cumulative sand volume changes for the inlet between successive surveys during the four years.

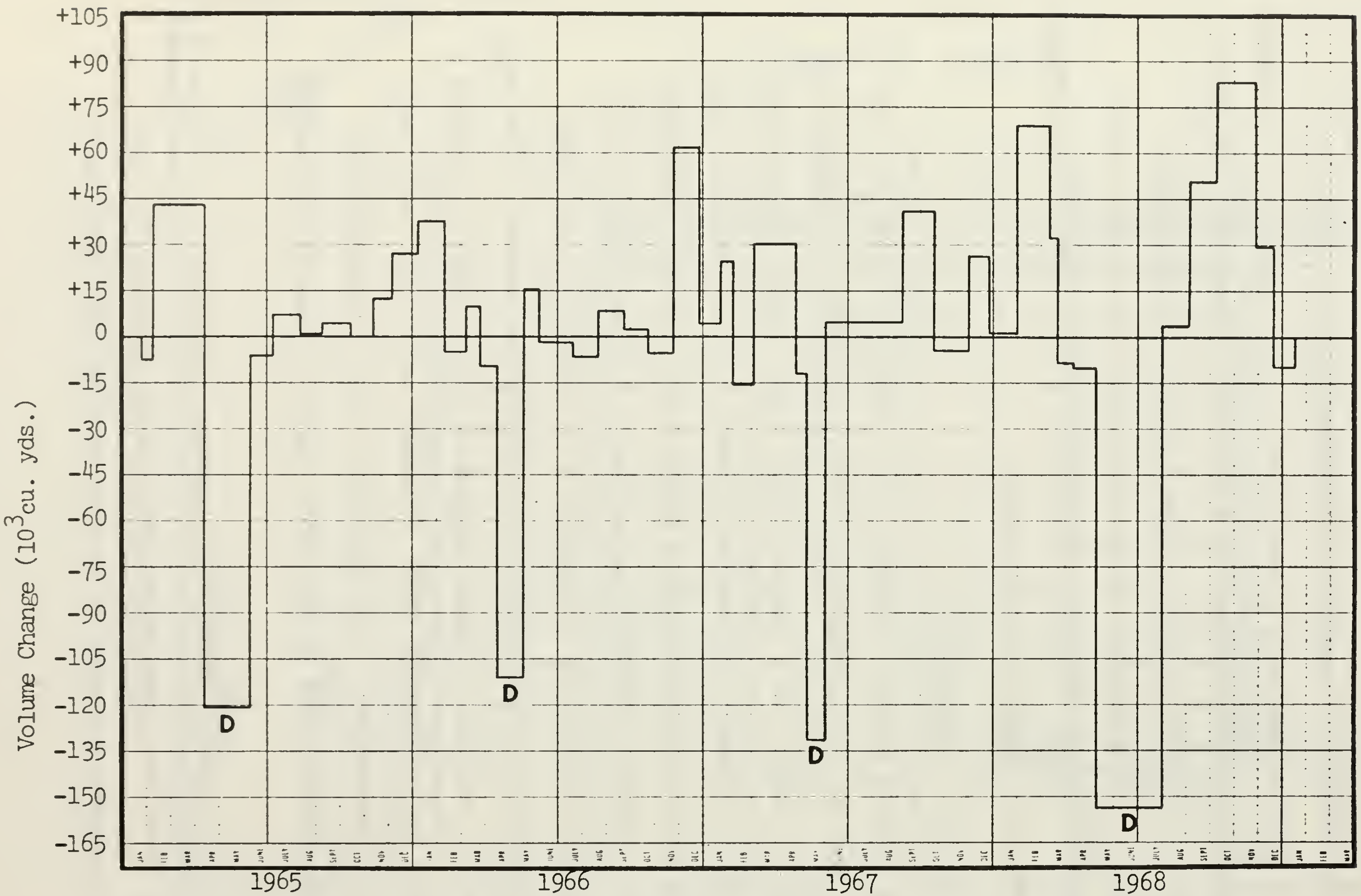

Figure 5: Sand Volume Changes Between Successive Surveys for the Inlet (D denotes dredging)

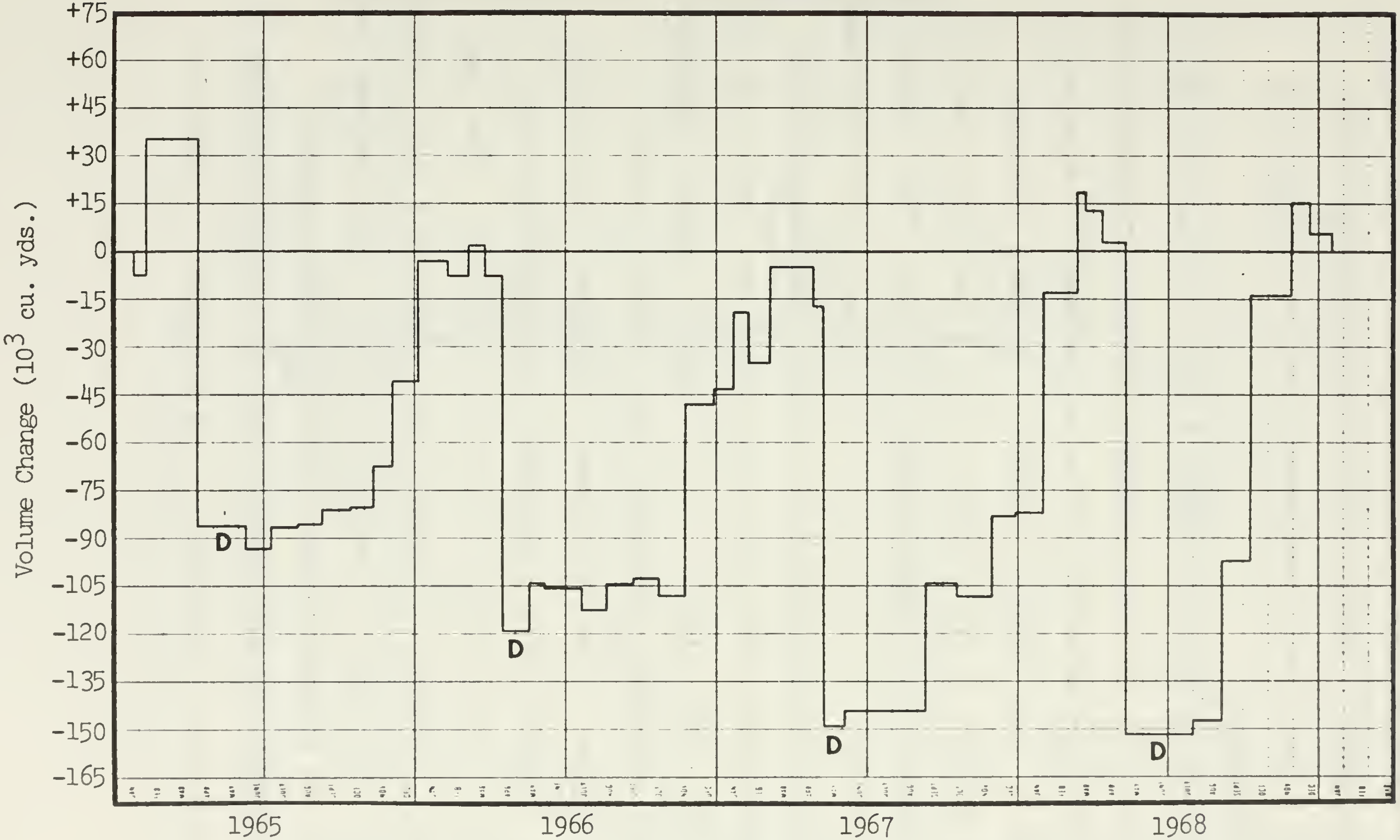

Figure 6: Cumulative Sand Volume Changes Between Successive Surveys for the Inlet (D denotes dredging)

During the one-year period between dredgings, or dredging year, the inlet experiences little or no shoaling during the summer months, then a rapid shoaling during the fall and early winter, and a decreased shoaling during later winter and spring.

The volume changes of Figure 5 were prorated according to the length of the time interval between surveys, and the average daily rates of fill thus encountered are graphed in Figure 7. The seasonal pattern of filling described above is evident in this graph, but it is apparent that the prorated daily fill rates are more variable. This variability probably reflects the occurrence and intensity of individual ocean storms occurring between surveys. The maximum fill rate observed was about 3,500 cubic yards per day (11 to 20 March 1968). This figure is equivalent to a daily shoaling of 0.15 ft throughout the whole inlet for that period.

From Figure 7, the histograms of Figures 8 and 9 were derived. Figure 8 is a histogram of average daily fill rates for the whole inlet during the four years. The same information is shown in Figure 9 in cumulative form. On the gain side, this figure shows that in half of the surveys the daily rate of filling exceeds about 800 cubic yards.

The computed annual rates of sand accumulation in the inlet, extracted from Figure 6, are presented in Table II.

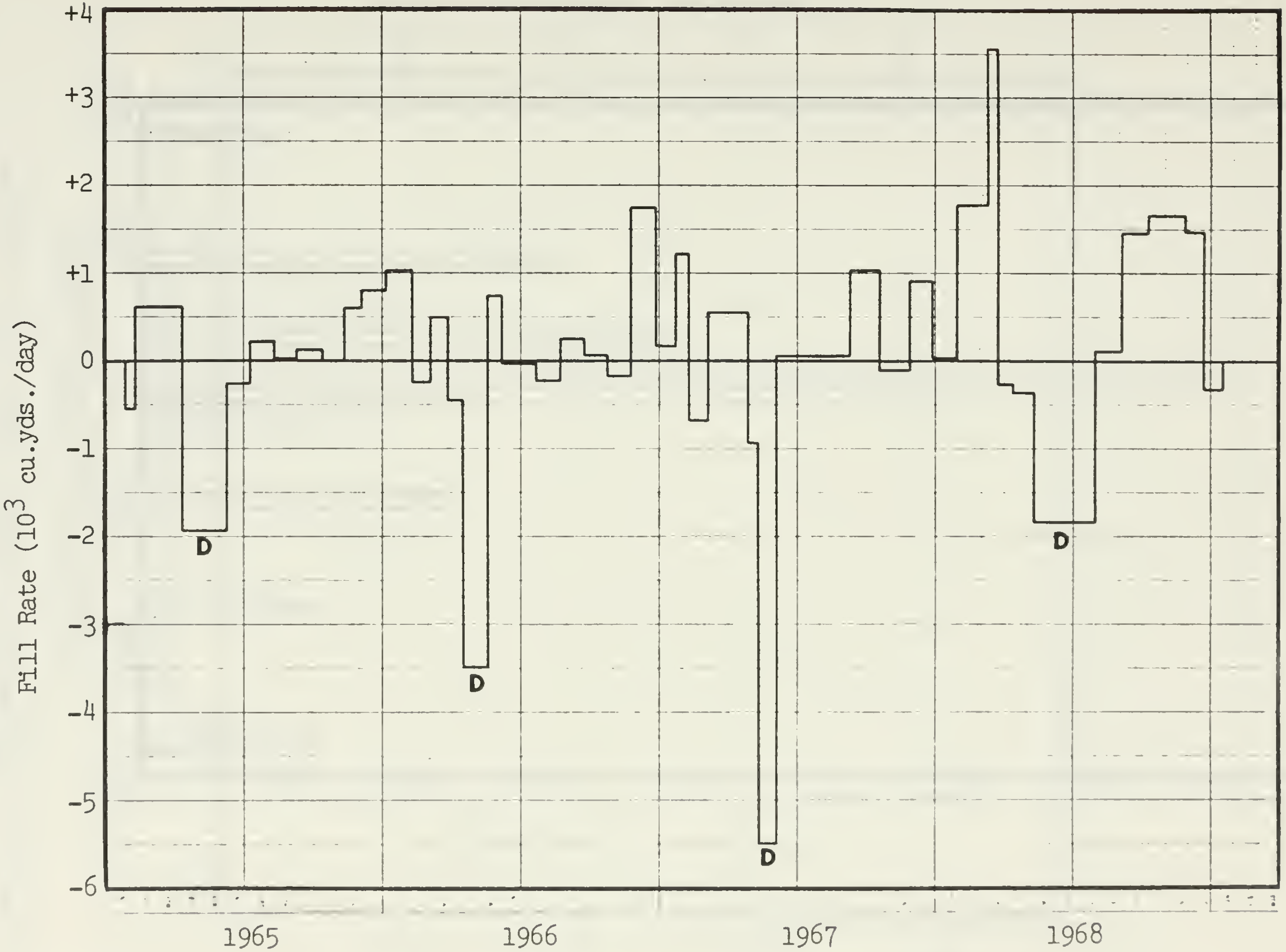

Figure 7: Daily Sand Volume Changes Between Surveys for the Inlet
(D denotes dredging)

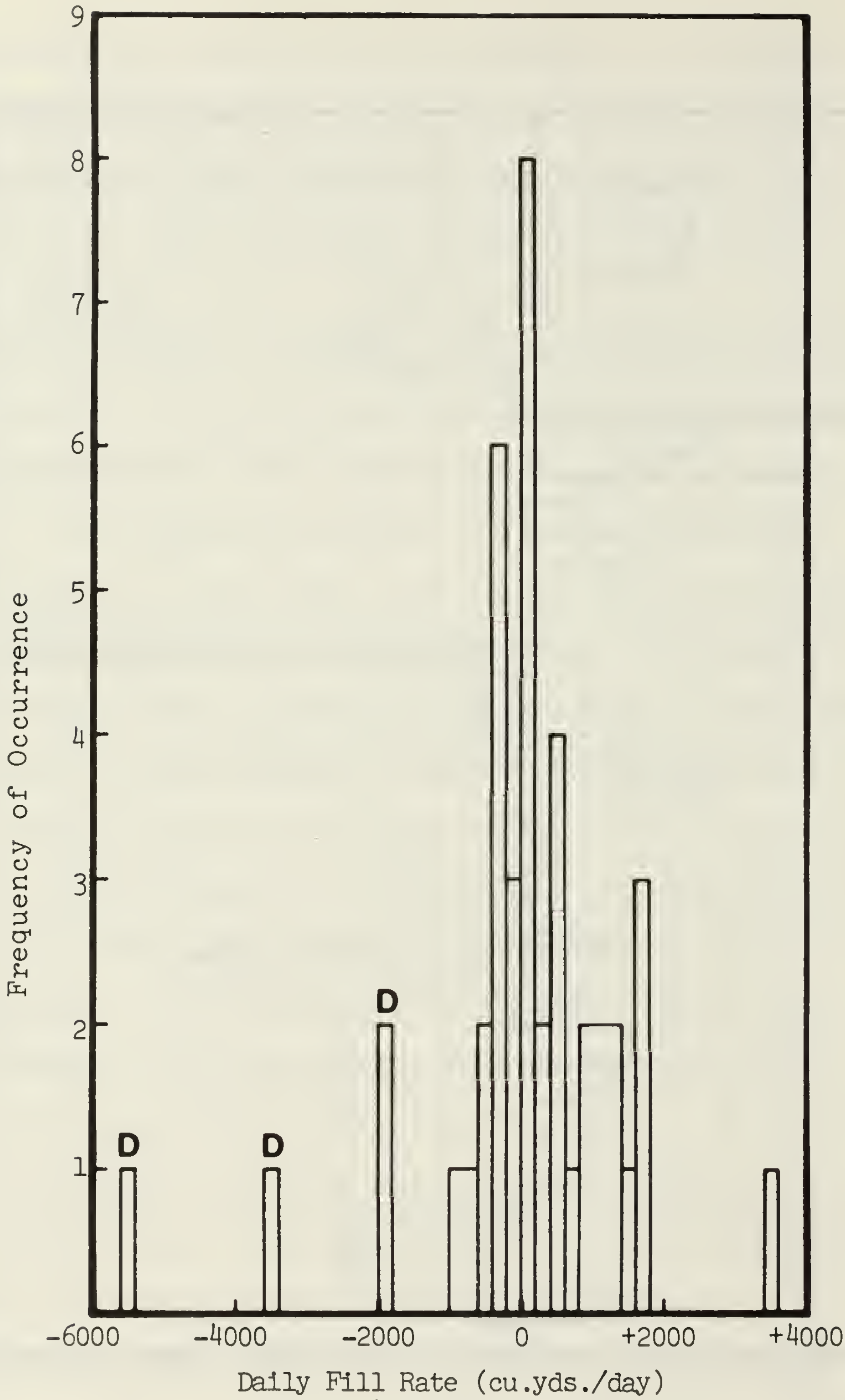

Figure 8: Histogram of Daily Sand Volume Change Between Surveys for the Inlet (D denotes dredging)

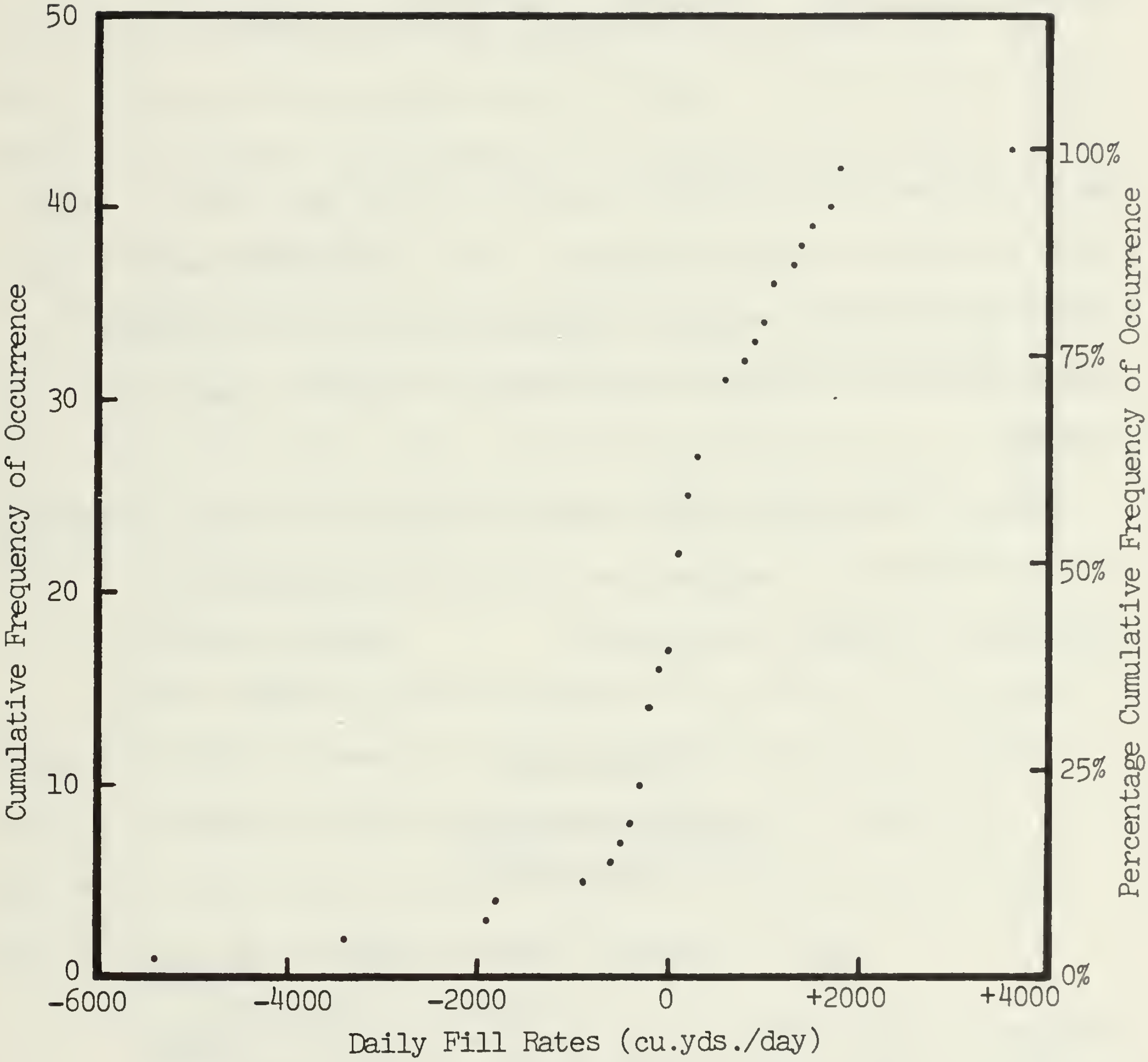

Figure 9: Cumulative Distribution of Daily Sand Volume Change for the Inlet

TABLE II

TOTAL SAND FILL FOR THE INLET PER DREDGING YEAR
(volumes in cubic yards)

1965-66	1966-67	1967-68	1968-69	Average
96,000	115,000	170,000	167,000	137,000

The total sand fill during the four years was 548,000 cubic yards giving an annual average of 137,000 cubic yards. The volume differences between dredging years are attributed to sand supply and transport differences from one year to another.

Table III presents the dredged volumes of sand according to the volumetric computations and to the contractor (Shellmaker Company) estimates.

TABLE III

DREDGED VOLUMES
(in cubic yards)

	1965	1966	1967	1968	Average
Computed	122,000	112,000	132,000	154,000	130,000
Shellmaker	146,000	97,450	114,025	135,720	123,300

These figures show a reasonable agreement between the two estimates. The average dredged volume of 130,000 cubic yards is of the same order of magnitude as the above quoted

average annual sand fill of 137,000 cubic yards, as should be expected. It should be noted that the dredged area extended a short distance seaward of the gridded area shown in Figure 4.

It is interesting to note in Table II the increasing trend of the yearly amounts of sand fill between 1965 and 1969. It may be also observed in Table III that the volumes dredged increased in proportion to the previous year's fill.

B. SPATIAL DEPENDENCY

Having established a definite seasonal pattern of filling for the inlet, inquiry was then made as to where and how the sand fills the inlet, i.e., what was the pattern of accumulation of the sediment within the inlet and in what manner did the filling take place.

1. Volume Changes

The computer was programmed to evaluate the volume changes between surveys in selected transverse and longitudinal volumetric sections of the inlet, providing an east-west and a north-south component of the rate of fill. The sections are designated in Figure 4.

a. Transverse Sections

Figure 10 is a graph of the sand volume changes between successive surveys for the transverse sections 1, 3, 5, and 8. These sections are presented because they best illustrate the manner of progressive filling from the

entrance of the inlet inward. It should be emphasized that the three outer sections are open-ended in at least one extremity.

Other than the seasonal pattern present in every section, as was expected, another feature is apparent when the four sections are compared. The range of volume change is smaller in Section 8, the innermost, than in the other sections. Significantly, the dredged volumes in Section 8 are also smaller, thus indicating less need to remove sand in order to get down to the intended dredging depth. This indicates that the sand does not penetrate in great quantities to the innermost reaches of the inlet in one year. It is also noticeable in Figure 10 that the volume changes between surveys in the four sections are generally in-phase. This reveals that the penetration and deposition of the sand takes place along the whole length of the inlet at the same time, although in different quantities. These findings are also illustrated in Figures 11 through 14 which show the cumulative sand volume changes for these sections during the four years.

The annual rates of sand fill in each of the ten transverse sections is presented in Table IV. The figures show that the greatest accumulation rate occurred in Sections 4 and 5 just inside the seaward end of North Jetty in three of the four dredging years. Thus it appears that the sand accumulates mostly in the outer half of the inlet.

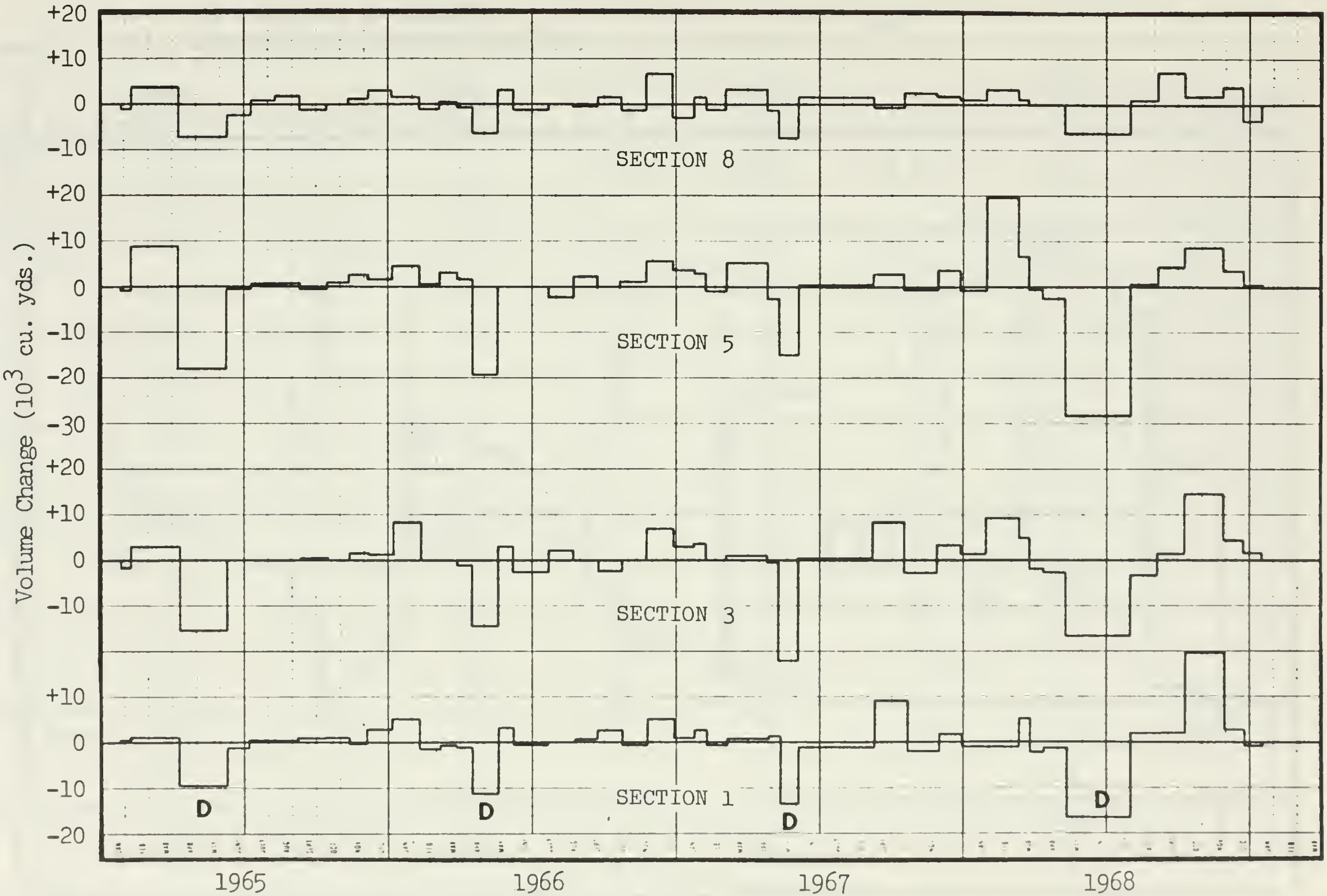

Figure 10: Volume Changes Between Successive Surveys. Transverse Sections (D denotes dredging)

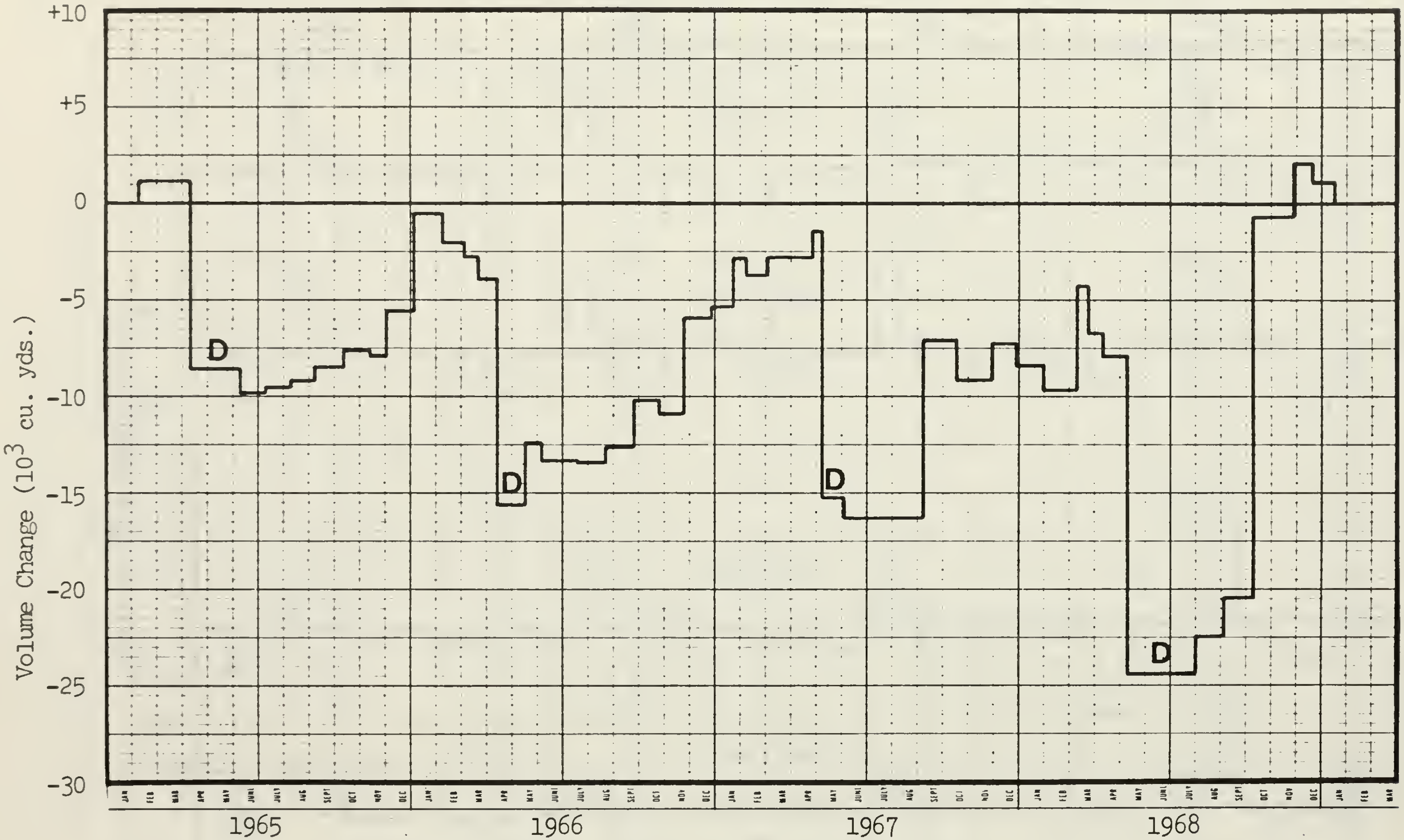

Figure 11: Cumulative Volume Changes – Transverse Section 1
(D denoted dredging)

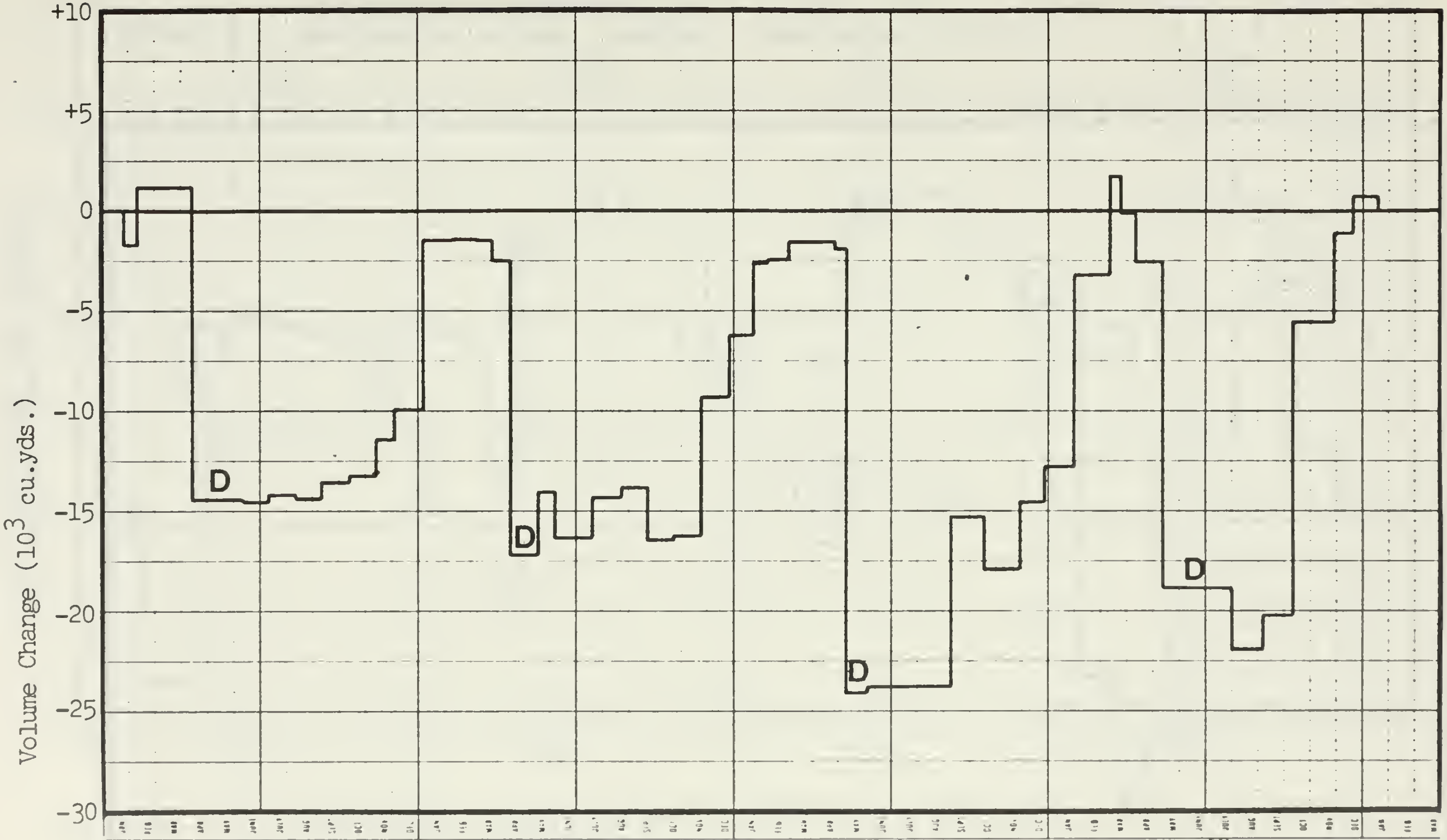

Figure 12: Cumulative Volume Changes — Transverse Section 3
(D denotes dredging)

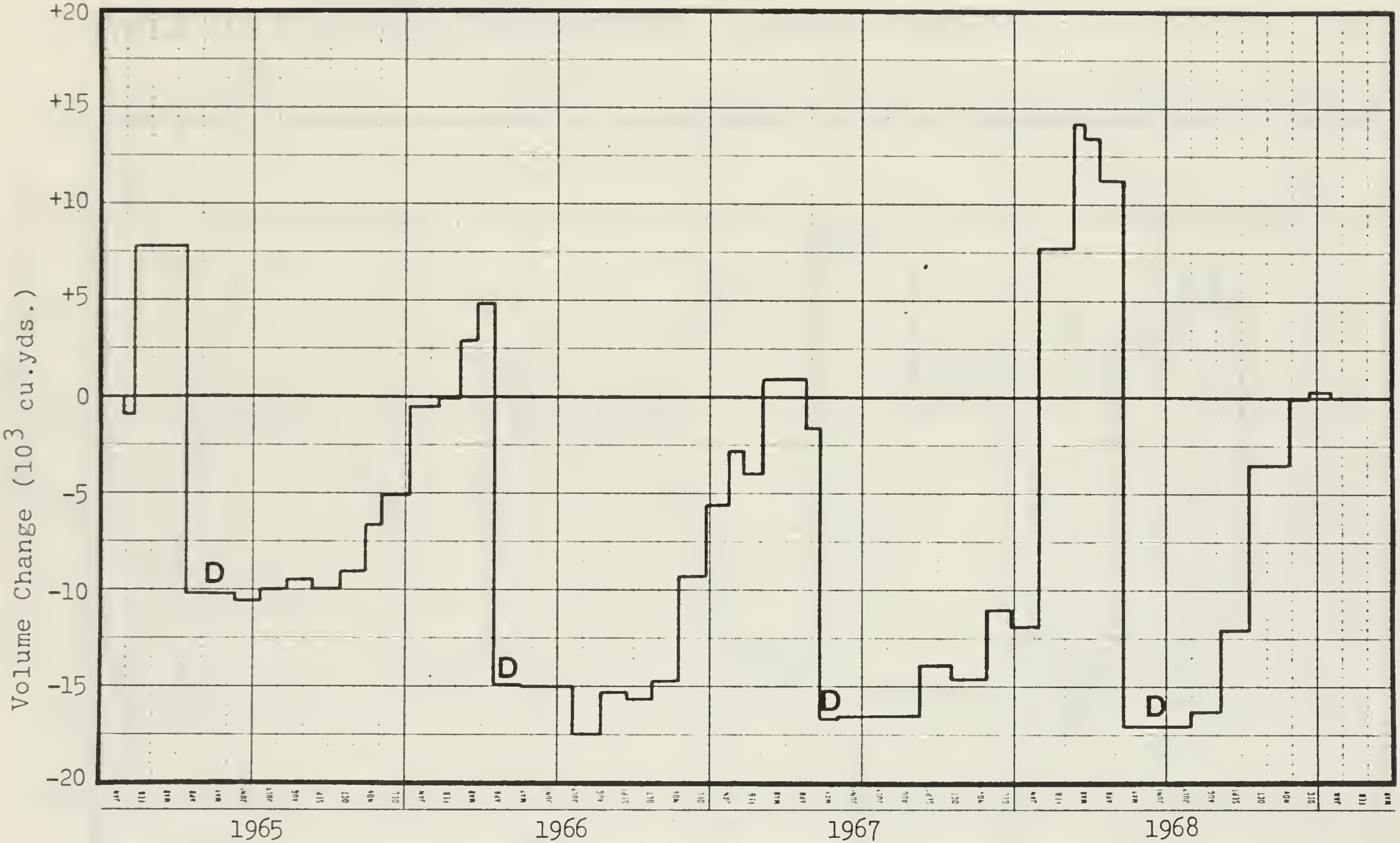

Figure 13: Cumulative Volume Changes — Transverse Section 5
(D denotes dredging)

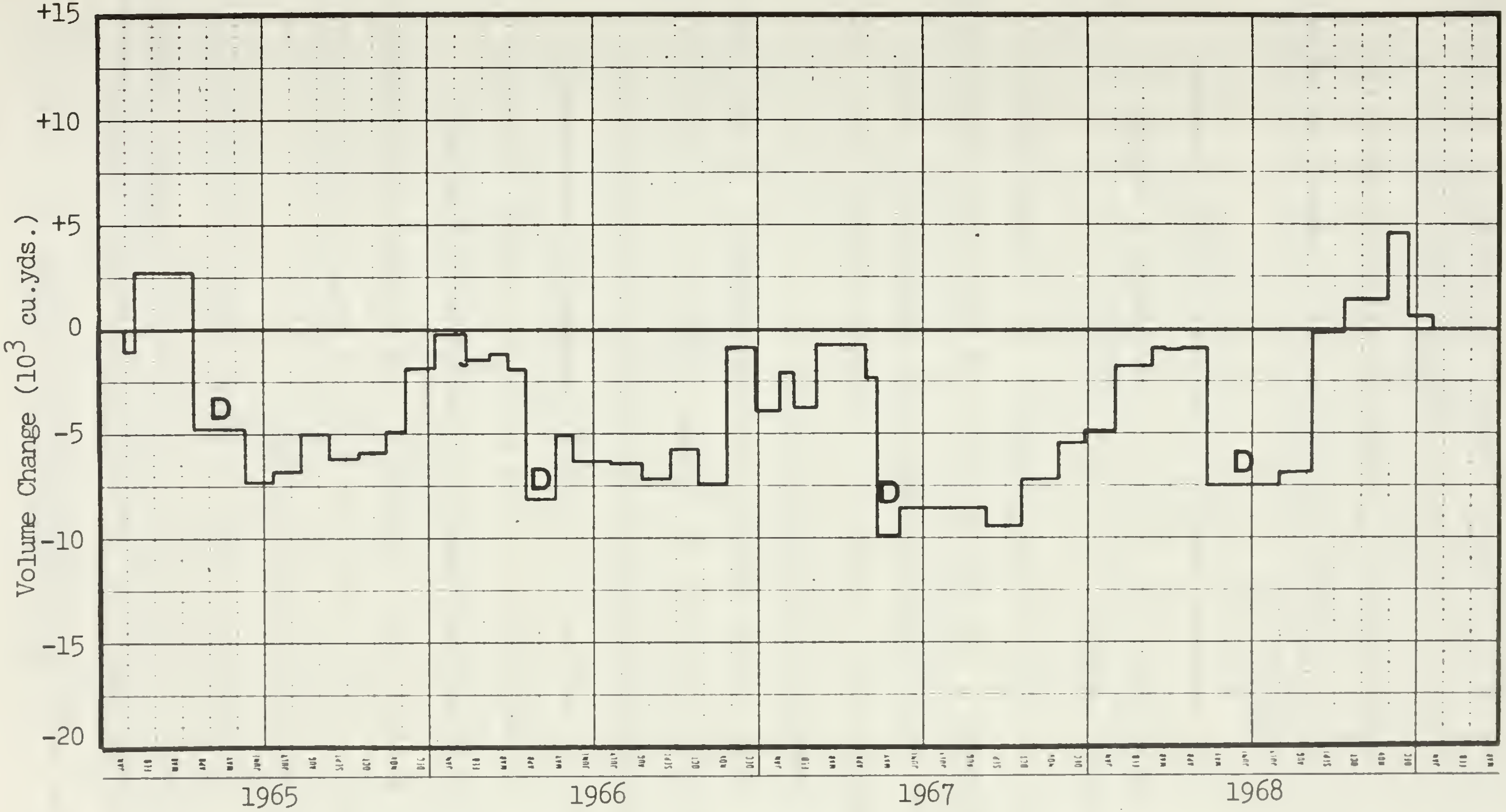

Figure 14: Cumulative Volume Changes — Transverse Section 8
(D denotes dredging)

b. Longitudinal Sections

The longitudinal sections selected to illustrate the manner of filling across the channel were numbers 2, 5, 8, and 11 (see Figure 4). The cumulative sand volume changes for these sections during the four years are shown in Figures 15 through 18.

The seasonal pattern is again very clearly present in Sections 2, 5, and 8. Section 11, however, differs in this respect; indeed, it seems to have a random distribution of sand volume changes. It is also apparent that this section, the southernmost of the four, experiences much smaller sand volume changes than the others. This section clearly lies outside the dredged channel since the effects of dredging are inconspicuous.

The volume changes between surveys in Sections 2, 5, and 8 are generally in-phase, meaning that deposition of sand occurs across most of the width of the inlet at the same time. Section 11 clearly behaves independently.

A comparison of the sand fill rates in each of the 12 longitudinal sections is presented in Table V. These results show that Sections 3 and 4 have the highest average rates of fill. This indicates that filling occurs most rapidly near the North Jetty.

It should be kept in mind that the volume computation for each longitudinal section, as for each transverse section as well, is an integration over the whole length of the section. Nevertheless, it may be concluded

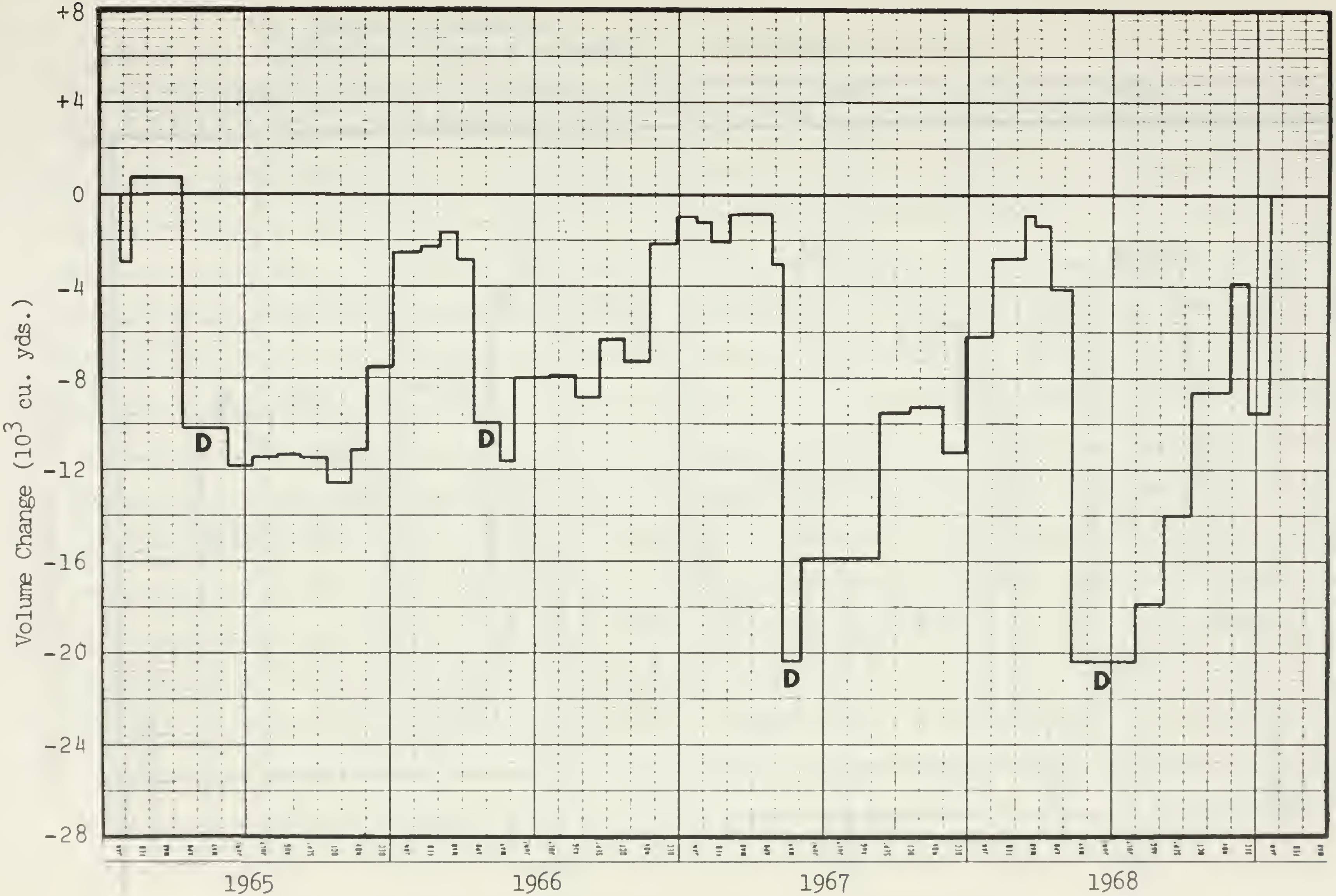

Figure 15: Cumulative Volume Changes — Longitudinal Section 2
(D denotes dredging)

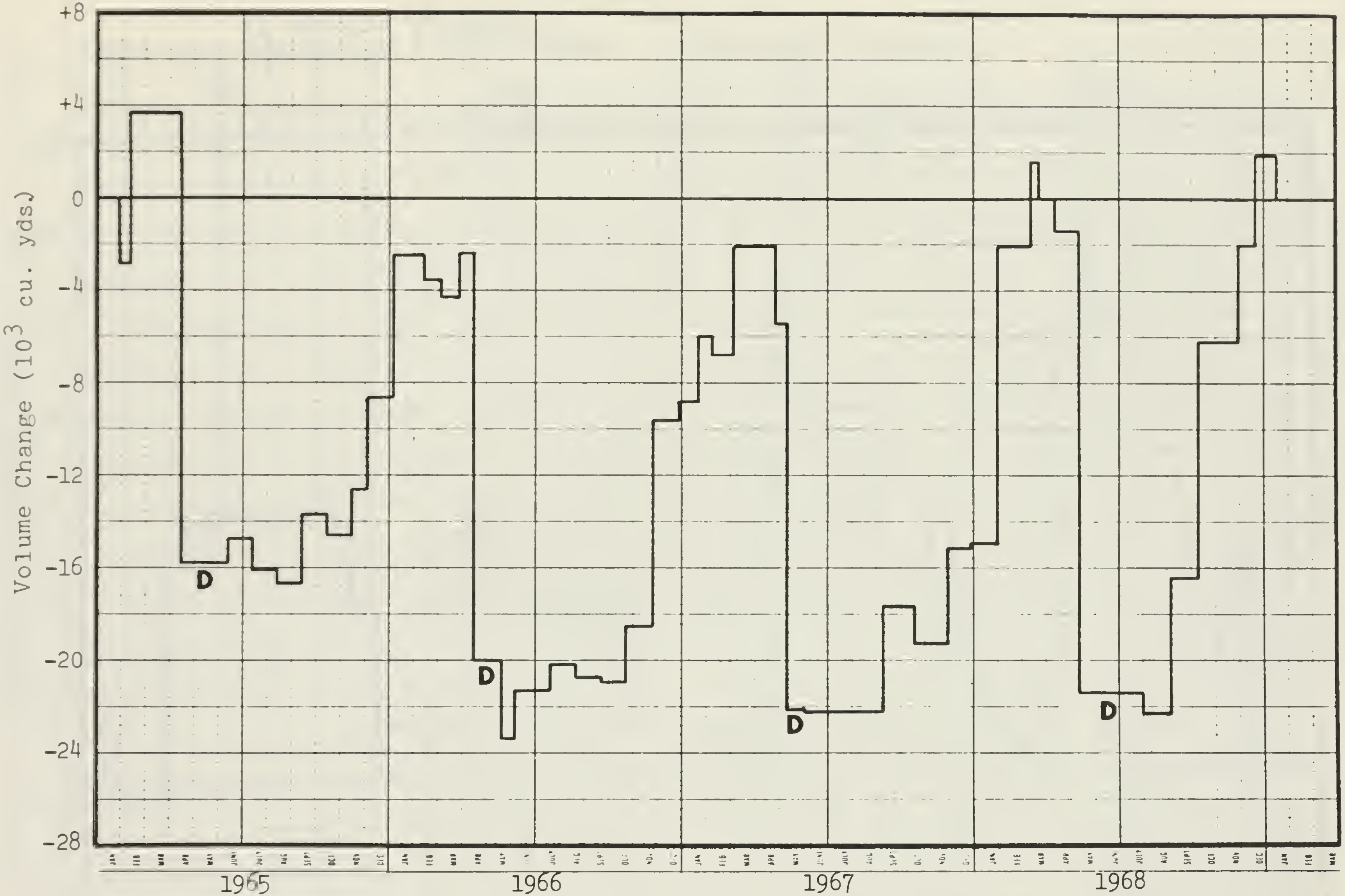

Figure 16: Cumulative Volume Changes — Longitudinal Section 5
(D denotes dredging)

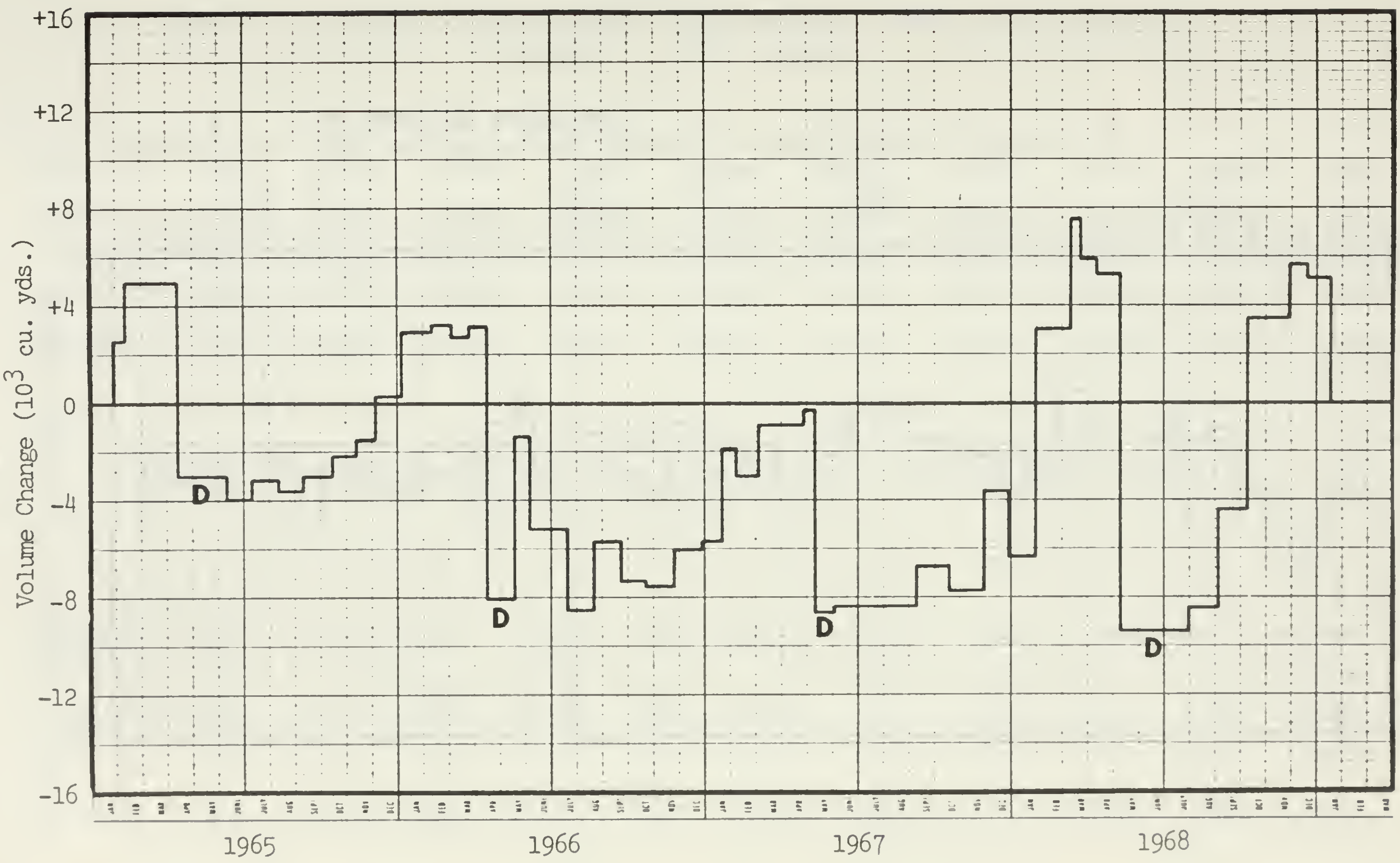

Figure 17: Cumulative Volume Changes – Longitudinal Section 8
(D denotes dredging)

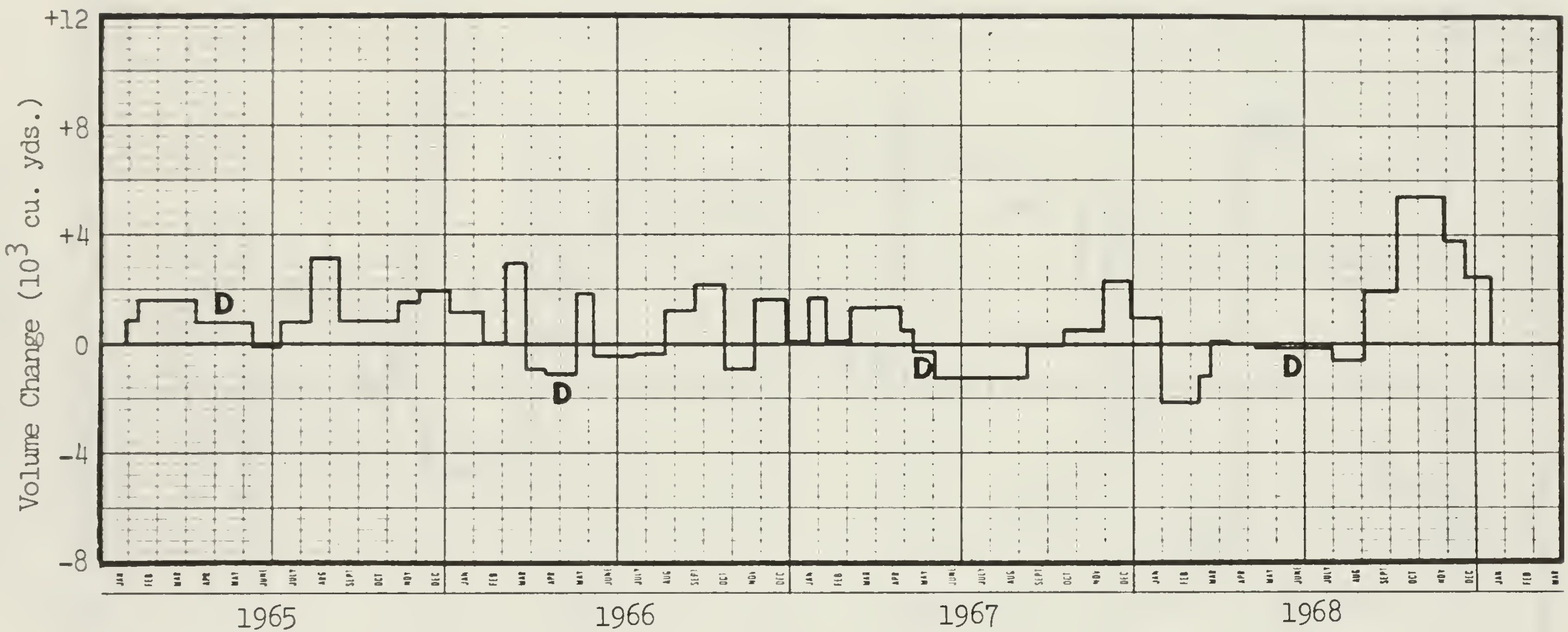

Figure 18: Cumulative Volume Changes – Longitudinal Section 11
(D denotes dredging)

TABLE IV

RATES OF SAND FILL PER DREDGING YEAR FOR THE TRANSVERSE SECTIONS
(volume in cubic yards)

	1	2	3	4	5	6	7	8	9	10
1965-66	9300	13000	13100	16600	15300	10600	7000	7000	7000	8000
1966-67	14200	15500	15600	18300	18500	13300	9600	7500	6100	6100
1967-68	12000	19700	26000	33000	30900	20400	10100	9100	8100	7700
1968-69	26500	26600	22600	20600	17300	18000	16200	12200	9300	8300
Average	15500	18700	19300	22100	20500	15600	10700	9000	7600	7500

TABLE V

RATES OF SAND FILL PER DREDGING YEAR FOR THE LONGITUDINAL SECTIONS
(volume in cubic yards)

	1	2	3	4	5	6	7	8	9	10	11	12
1965-66	3100	11000	17900	17600	14300	12000	9400	7100	6800	5500	4100	3600
1966-67	2300	10800	23300	26000	21300	14900	10200	8300	9000	6600	3300	3200
1967-68	6200	19400	28000	27400	23800	20900	19600	16200	10300	4300	4400	3000
1968-69	5600	16600	24500	25600	24200	20700	17400	15100	15300	10800	6000	4600
Average	4300	14400	23400	24200	20900	17100	14200	11700	10400	6800	4500	3600

that the area of maximum sand accumulation over one dredging year lies approximately at the intersection of the transverse and longitudinal sections having the maximum rates of fill. This places the general area of greatest fill about 200 feet east of the seaward end of the North Jetty.

2. Channel Migration and Depth Change

Having determined where in the inlet the highest rate of shoaling occurred, the attempt was made to understand in more detail how the sand accumulated. To accomplish this, the migrations of the channel axis and its depth changes were examined for the four years. It is appropriate to note here that a single channel axis was found in nearly all surveys.

Both the location and depth of the channel axis and the width of the channel were determined from the bathymetric charts shown in the Appendix for four representative transverse transects. The transects selected are located at the entrance (0 ft range line), 200 ft range line, 500 ft range line, and 800 ft range line (Figure 4). The data for these transects are presented in Figures 19 through 22. The channel width was defined by the horizontal distance measured in the transverse direction between the pair of contours having an elevation of one foot above the channel axis.

An examination of the graphs reveals, first of all, the seasonal pattern already described, although the pattern

Figure 19: Channel Location and Depth — 0 ft Range Line Transect
(D denotes dredging)

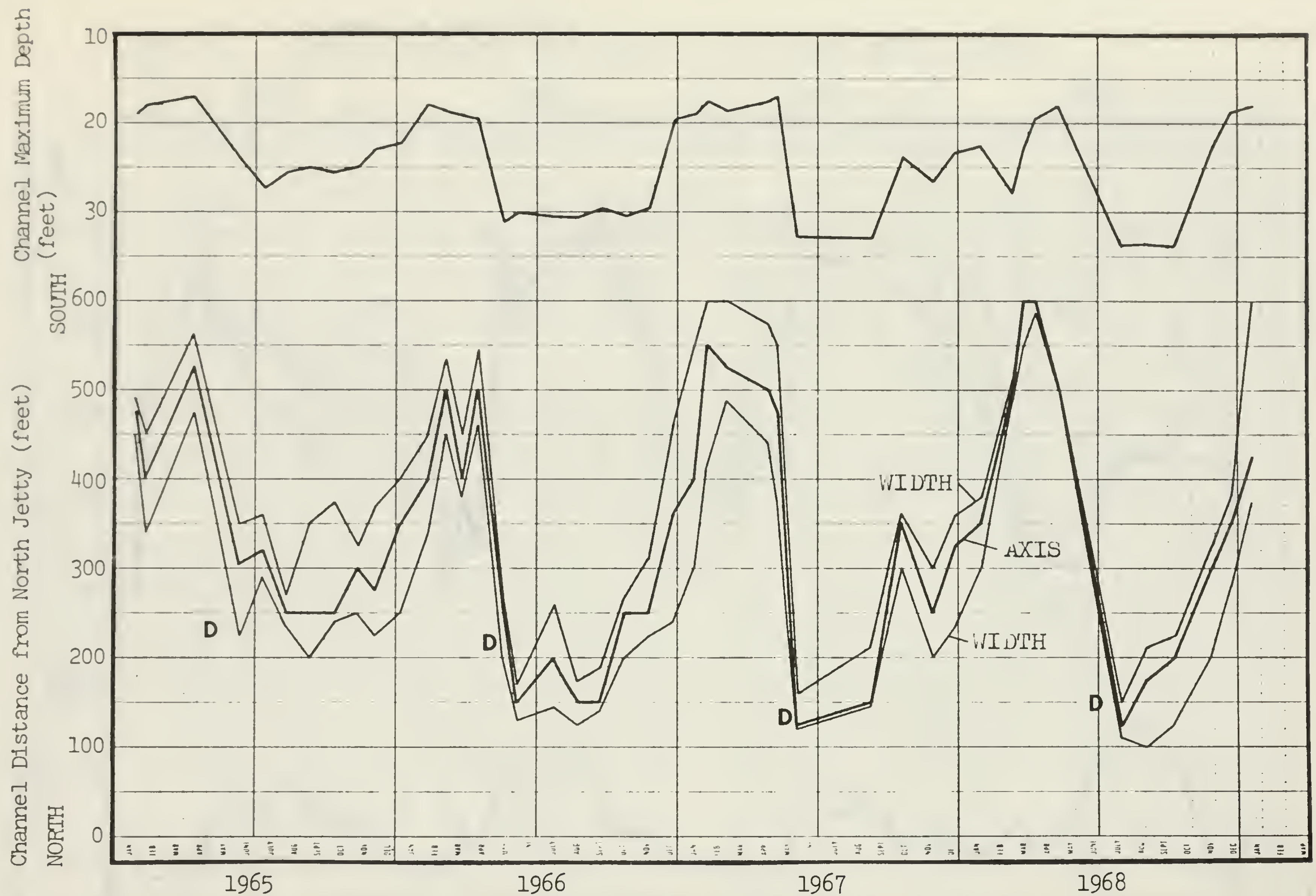

Figure 20: Channel Location and Depth – 200 ft Range Line Transect
(D denotes dredging)

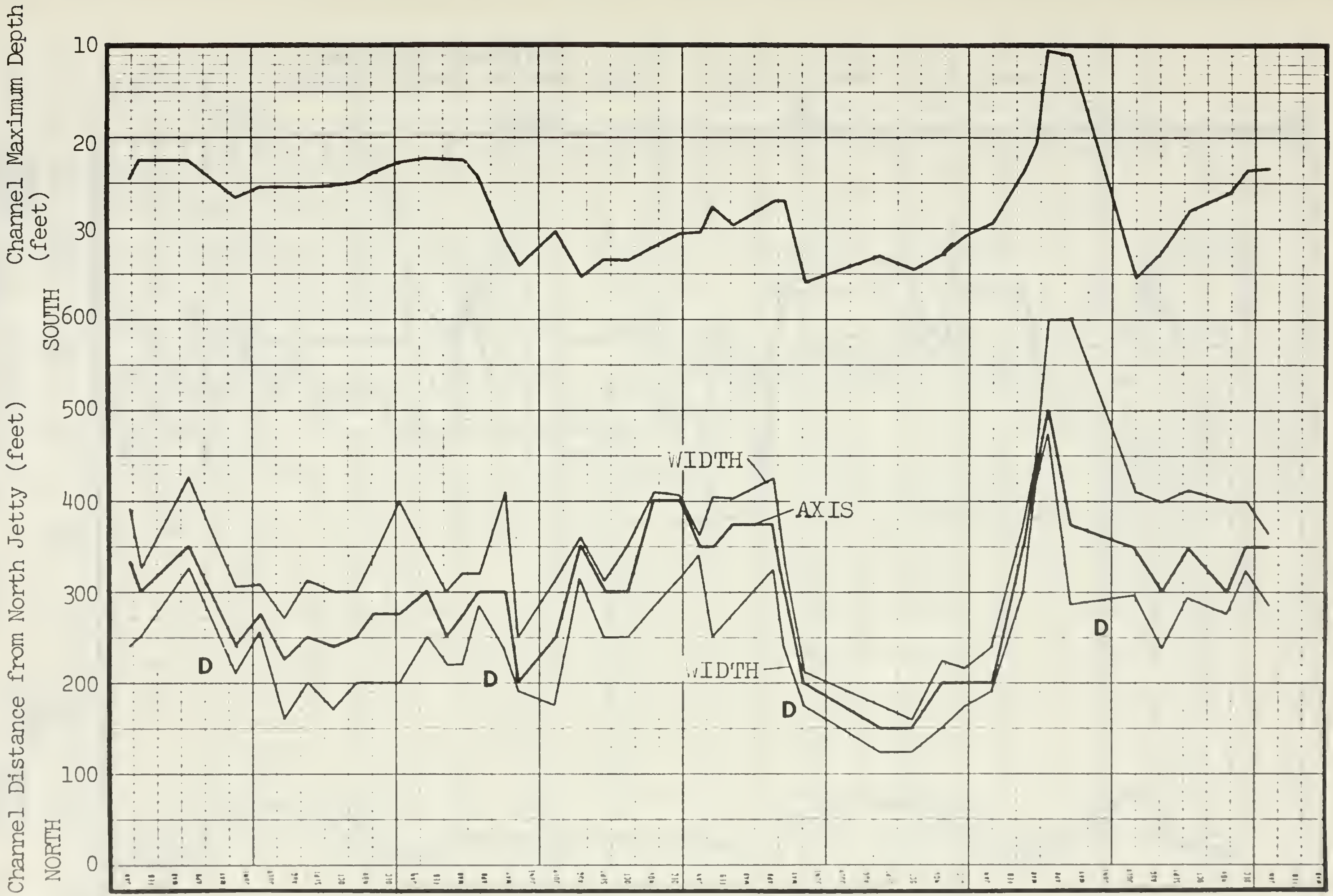

Figure 21: Channel Location and Depth – 500 ft Range Line Transect
(D denotes dredging)

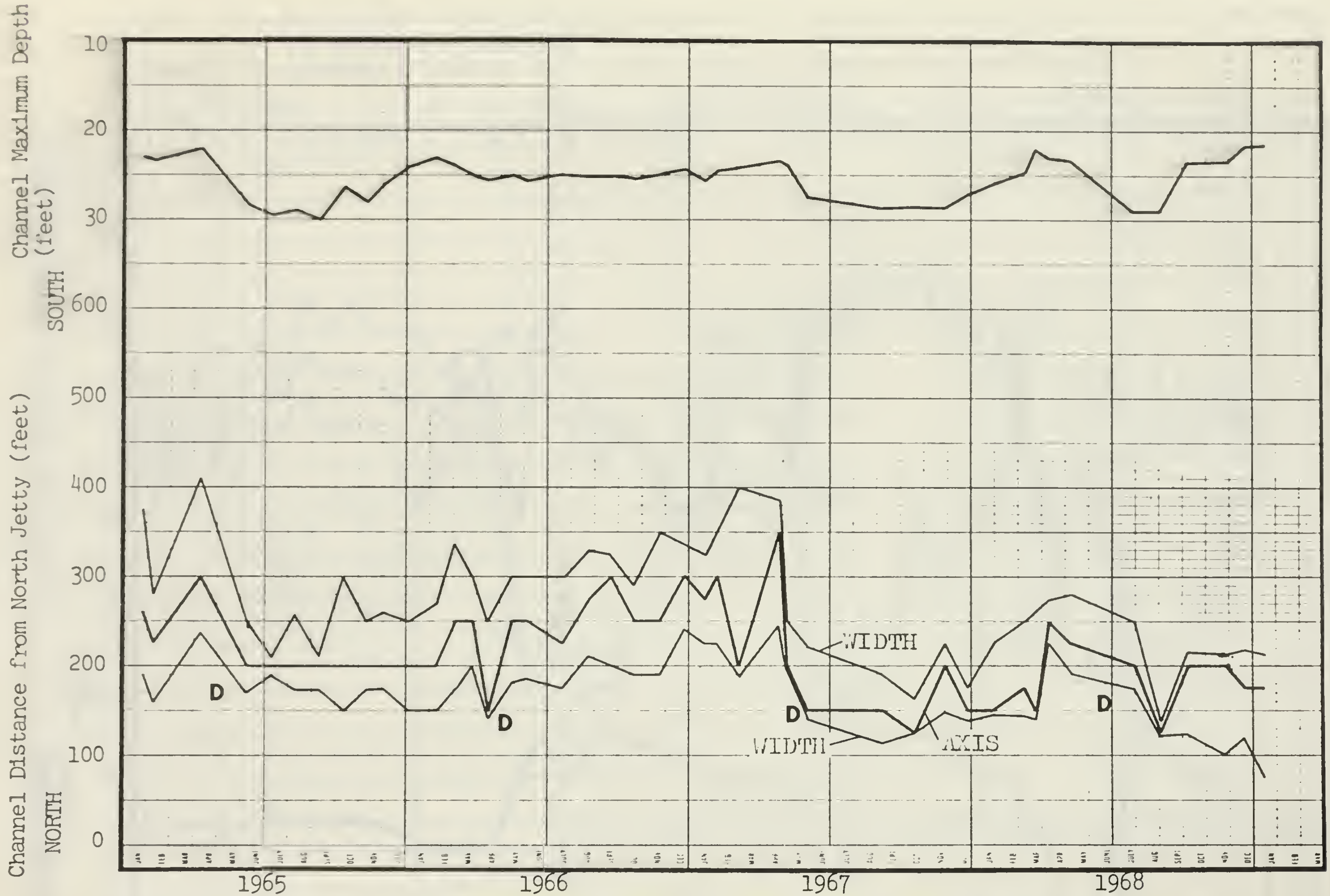

Figure 22: Channel Location and Depth — 800 ft Range Line Transect
(D denotes dredging)

is subdued in the innermost part of the inlet. It is apparent in both the channel migration and channel axis depth.

The channel axis migration is the most revealing feature of these graphs. In each transect, particularly the outermost ones, it can be seen how, after the yearly dredging which placed the channel axis close to the North Jetty, the channel moved southward, very slowly at first during the summer, then very rapidly in the fall, attaining its southernmost position in the winter or spring before the next dredging. This clearly indicates that the entrance channel is being filled along the north side, particularly at its seaward end. The magnitude of the seasonal movement of the channel in these four transects for the four years is summarized in Table VI.

The width of the channel, represented in Figures 19 through 22 by the envelope around the channel axis, does not seem to yield much information. It was expected that the channel would be widest immediately after dredging and that it might become increasingly narrow as it filled; however, no pattern could be delineated from the graphs.

With regard to the depth of the channel axis, the graphs show that the seasonal changes of the channel axis depth are smallest in the innermost 800 ft transect. This is consistent with what was found in the study of the transverse volume sections; namely, that less sand accumulates in the innermost regions of the inlet. Table VII also demonstrates this observation.

TABLE VI

SOUTHWARD MIGRATION OF THE CHANNEL AXIS
IN EACH DREDGING YEAR FOR RANGE LINES
0 FT, 200 FT, 500 FT, 800 FT
(in feet)

	0	200	500	800
1965-66	280	250	75	100
1966-67	350	400	200	150
1967-68	325	475	350	125
1968-69	100	300	50	75
Average	264	356	169	113

TABLE VII

DECREASE IN CHANNEL AXIS DEPTH IN EACH
DREDGING YEAR FOR RANGE LINES 0 FT,
200 FT, 500 FT, 800 FT
(in feet)

	0	200	500	800
1965-66	12	9	5	7
1966-67	12	14	8	2
1967-68	6	15	26	7
1968-69	18	16	12	7
Average	12	14	13	6

It is noticeable in Tables VI and VII that the southward migration of the channel axis and the amount of shoaling of the channel had maximum values in the 200 ft transect. This is not surprising, since this transect crossed the general area of maximum sand accretion.

3. Contour Migration

It was felt that a study of the movement of the bottom contours between successive surveys would be helpful in the understanding of the configuration which the sand body assumed as it deposited. That is, did the sediment accumulate as a progressing sand fill and if so, did it migrate across or along the inlet; or did it tend to fill the deepest areas first, producing a flat bottom as it piled up? In the first case, the sand would progress as a steep "front", keeping its advancing slope relatively constant. In the second case, the sand would present gentler slopes and would shoal the channel axis more heavily.

It is readily apparent from the series of sounding charts contained in the Appendix that the inner half of the inlet fits the first model and the outer half follows the second. To illustrate this fact Figure 23 was prepared to show a time series of the -20 ft contour utilizing selected surveys between the dredgings of 1967 and 1968. It clearly shows how the sand mass encroaches rapidly across the inlet from the north end of the North Jetty. It may also be seen that the sand moves into the inlet along the

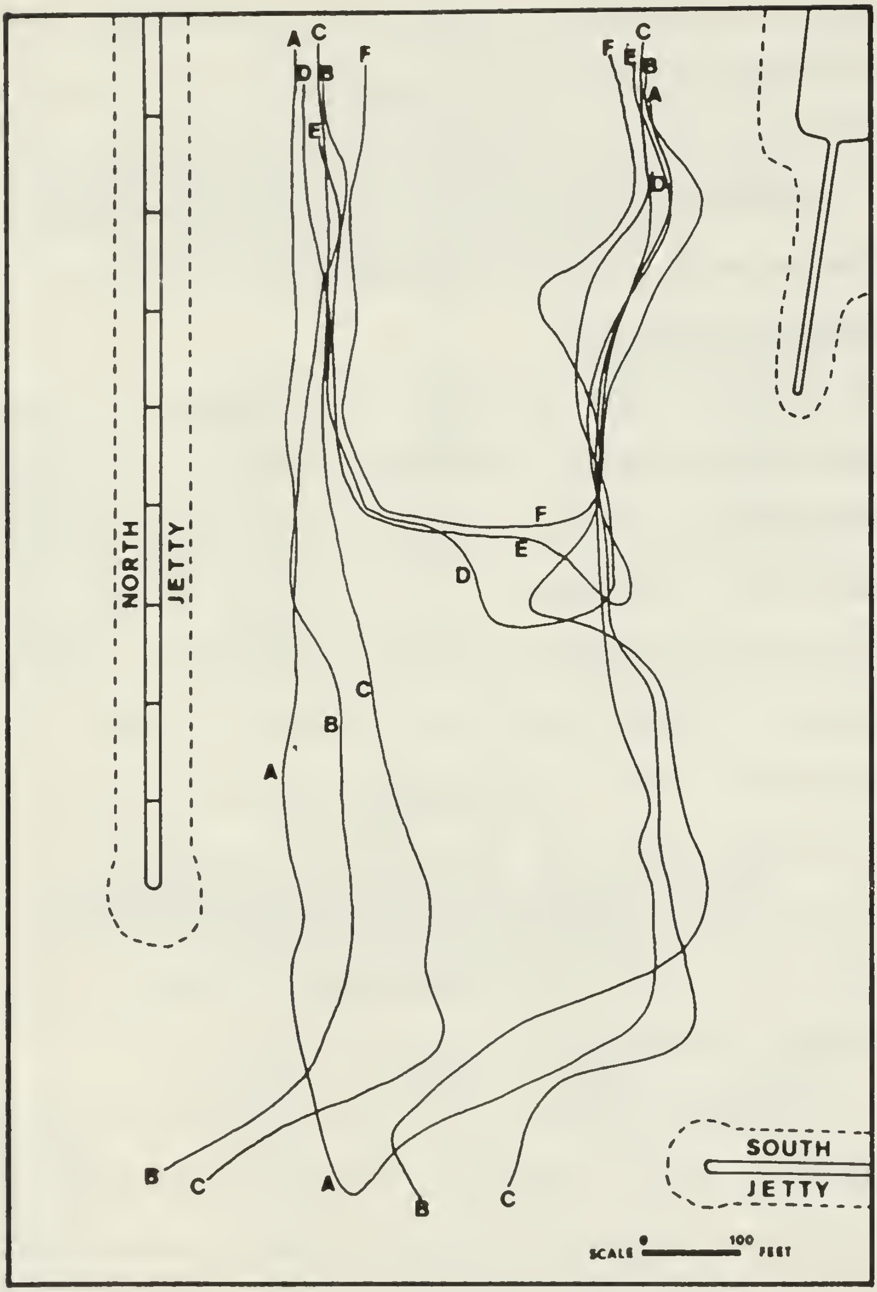

Figure 23: Position of the -20 ft Contour From Surveys in 1967-68

A - 2 June 1967
B - 17 October 1967
C - 31 January 1968
D - 11 March 1968
E - 20 March 1968
F - 11 April 1968

North Jetty, progressing very little into the inner half of the inlet. The survey charts for 31 January and 20 March 1968 (see Appendix) show particularly well the gentle slopes of the fill in the exposed harbor entrance and the steep slopes in the quieter water inside the inlet.

These concepts were further examined through analysis of the migration of selected bottom contours along transects taken at the 200 ft and 500 ft range lines. The contours chosen were 10 ft, 16 ft, and 20 ft; they were selected for their representativeness and because they were also present most of the time in the transects. Figures 24 and 25 show the graphs thus constructed.

Figure 25 reveals that in the 500 ft transect the contours adjacent to the North Jetty stay packed together as they advance with a high slope across the inlet after a dredging. The same contours on the south side indicate a much gentler slope and don't migrate. The year 1968 seems to have been exceptional in that the 20 ft contour moved completely across the inlet whereas in the previous years it went only as far as the mid-point of the inlet. Examining Figures 25 and 21 jointly, the seasonal history of the sand movement across the transect becomes even clearer. It can be seen that dredging produces a steep slope along the north side of the inlet. The sand "front" progresses from the north and shoals the channel as it pushes the axis toward the south.

Similar conclusions can be drawn for the inner transects since the behavior of the contours on the sounding charts is very similar to that on the 500 ft transect, with the exception that the rate of contour migration is less.

Figure 24 depicts the migration of the contours in the 200 ft transect. It is readily apparent how different this graph is from Figure 25. The contours on both sides of the inlet, after being separated through deepening of the channel by dredging, remain separated through the summer months until they join in the fall due to sand accumulation. At this time of the year the slope of the southward encroaching sand body is fairly gentle. The sand doesn't creep along as a slip face; instead it tends to settle on the bottom with a gentle slope. On the south side of the inlet there is no evidence of sand deposition, the contour movement possibly responding to variations in the waves passing through the entrance to the spending beach. As in the previous case, the joint examination of Figures 24 and 20 for the 200 ft transect will provide a more complete picture.

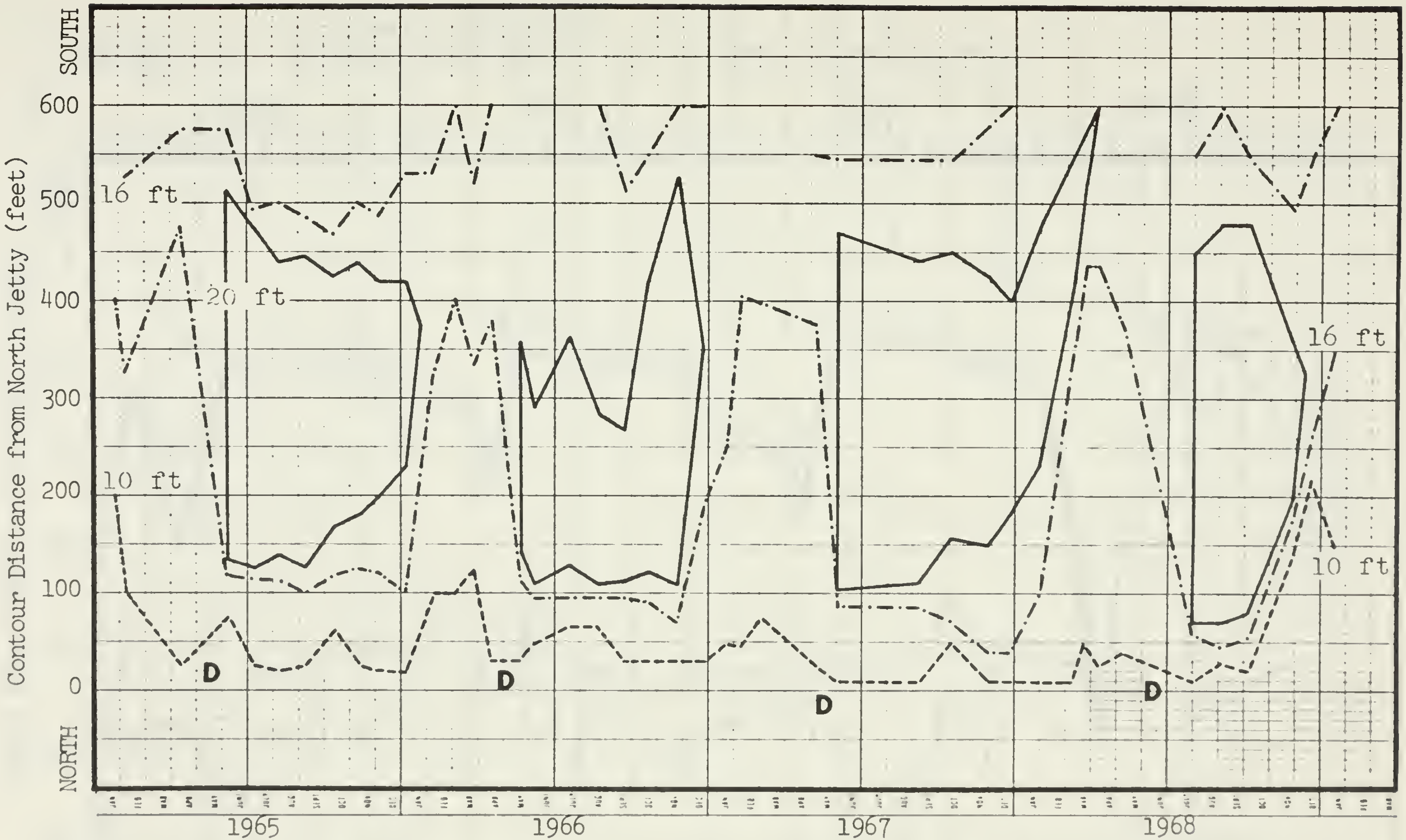

Figure 24: Selected Contours – 200 ft Range Line Transect
(D denotes dredging)

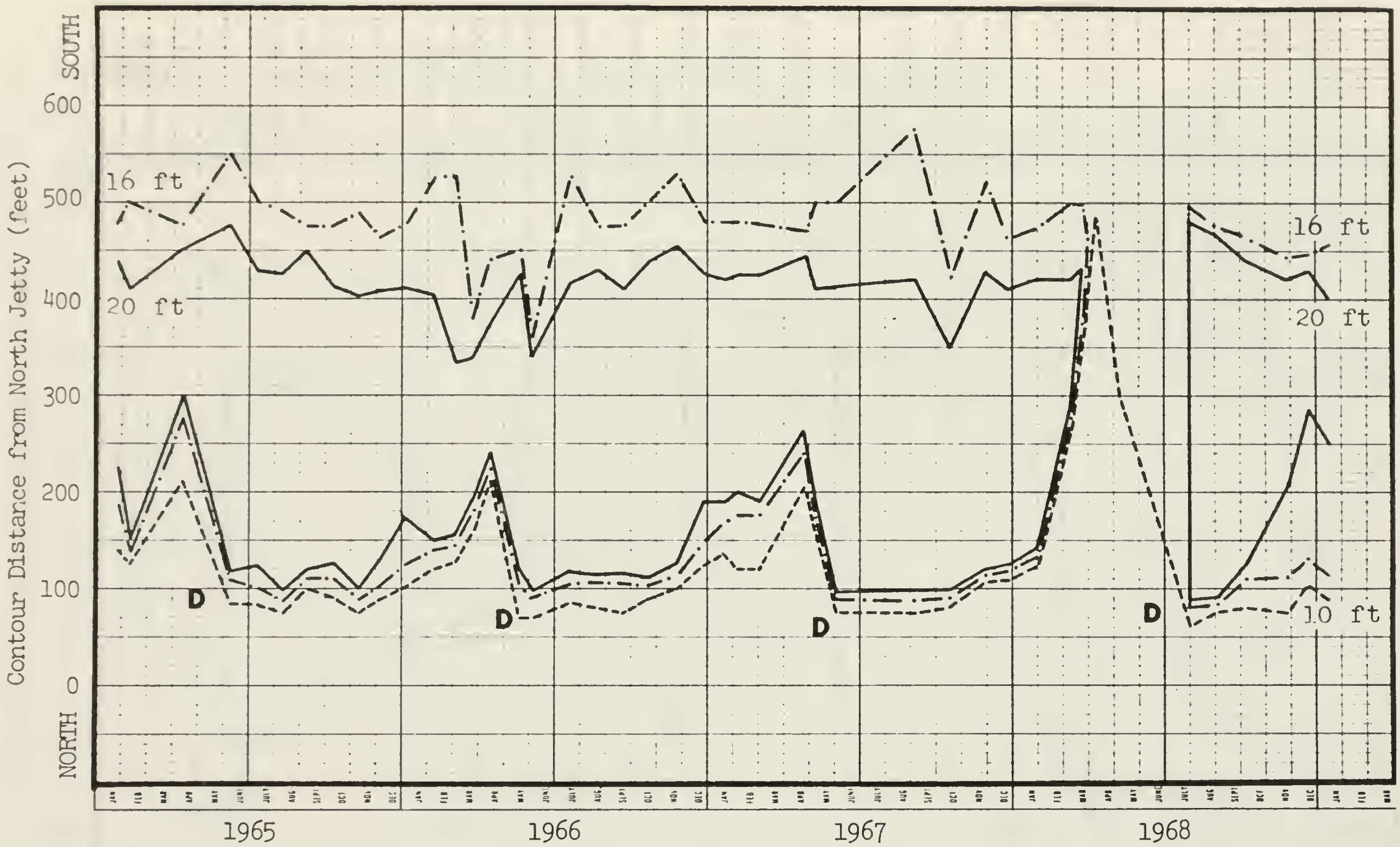

Figure 25: Selected Contours — 500 ft Range Line Transect
(D denotes dredging)

V. INTERPRETATION

The final questions that were considered had to do with the source of the sand shoaling the entrance, the mechanism of sand supply, and the reason for the patterns of sediment accumulation observed.

A. THE SAND SUPPLY

The fact that the greatest fill rates occur on the inside of the North Jetty at a location some 200 ft from its seaward end in the shelter provided from the dominant westerly waves (note Figure 4) points to downcoast littoral drift as the principal source, if not the only source, of the sediment which shoals the Ventura Harbor inlet.

Upcoast drift on this coast is presumed to occur in the summer associated with Southerly Swell (Oceanographic Services, Inc., (Phase II), 1965); however, there is no evidence of any accumulation in the lee of the South Jetty or anywhere else in the inlet in that season. It may be concluded that these waves are ineffective, partly because of their low frequency of occurrence, in shoaling the harbor. In view of the latter consideration it is interesting to notice that about one half mile downcoast the Santa Clara River contributes on the average an estimated 600,000 cubic yards per year to the littoral sand supply (Department of Water Resources, 1969).

It was pointed out that the estimated net annual littoral drift rate downcoast in this area is 400,000 cubic yards. The average annual deposition in the inlet is 137,000 cubic yards, which represents about one third of that amount.

B. DYNAMIC EQUILIBRIUM CONSIDERATIONS

The dynamic equilibrium condition of the inlet involves the concept of tidal prism and equilibrium throat area. The tidal prism of a body of water in connection with the ocean is given by the volume of water that passes through the inlet on flood or ebb tides. It is equal to the product of the area of the water body by the tide range. O'Brien (1931) developed a relationship between the tidal prism and the throat area of an inlet, or minimum cross-sectional area of the inlet below Mean Sea Level, when the inlet is in equilibrium with its hydraulic environment, i.e., when the scouring action of the tidal currents keep the throat area constant over a period of time.

In this thesis O'Brien's relationship is applied to the entrance of the Ventura Harbor inlet, and the following results are obtained:

$$\frac{P}{A} = 2.4 \times 10^3 \; P^{0.15} \text{ (ft)} \qquad \text{(O'Brien, 1931)}$$

$$P = ah \text{ (cu ft)}$$

where

$a = 740 \times 10^4$ sq ft, area of harbor

$h = 5.4$ ft, diurnal tide range (MHHW-MLLW)

$A = 1{,}200$ sq ft, equilibrium throat area (below MSL)

The throat area of the entrance below Mean Sea Level was considered for the most shoaled condition encountered during the four years, namely at the peak of the shoaling season in 1968 (survey of December 18); the value was 9857 sq ft below MSL. A comparison of this figure with the theoretical equilibrium value of 1,200 sq ft proves to be on the order of 8 times larger. This means that the Ventura Harbor inlet, even when filled with a year of sand accumulation, had not reached dynamic equilibrium and that the entrance might be expected over a period of years in the absence of dredging to become considerably shallower.

C. THE MECHANISM

Two agents can be responsible for the shoaling process at Ventura Marina, namely tidal currents and waves.

The fact that the cross-sectional entrance area is well in excess of the hydraulic equilibrium area implies that tidal current velocities in the inlet are weak. An estimate of the maximum tidal current through the entrance was made for several ranges of the tide. The volume of water passing

through the entrance was equated to the tidal prism of the harbor for a one-hour period around the time of maximum water-level change. The tidal curve was considered to be a sine wave of semi-diurnal period 12.4 hours. The maximum water level change in one hour is 1/4 the tide range. The results were as follows:

$$v = \frac{a}{4}\frac{h}{A} \quad \text{(ft/hr)}$$

where

$a = 740 \times 10^4$ sq ft, area of harbor

$A = 9857$ sq ft, throat area of entrance below MSL at maximum shoaling

h = tide range

v = tidal current velocity

For h = 10 ft, the largest observed tide range, v = 0.52 ft/sec;

for h = 5.4 ft, diurnal tide range, v = 0.28 ft/sec; and

for h = 3.7 ft, mean tide range, v = 0.19 ft/sec.

These values of tidal current velocity under the most extreme shoaling condition observed were entered on a sediment transport graph for steady unidirectional flow (Coastal Engineering Research Center, 1966, page 155) to see whether tidal currents alone should be expected to move sand. All velocities proved to be non-eroding, with the exception of

the extreme tide condition. Indeed, at a velocity of 0.52 ft/sec a steady current just begins to move sand of particle diameters between 0.18 and 0.7 mm. The sand in the inlet has an average median grain diameter of about 0.2 mm (Oceanographic Services, Inc., (Phase II), 1965). It must be noted that the extreme tide range was observed only once at adjacent tide stations (National Ocean Survey, 1962 and 1968), and is certainly a unique situation.

Thus, waves remain as the main cause for the shoaling. Independent evidence to support this conclusion is provided by the correlation between the seasonal volume shoaling of the inlet shown in Figure 5 and the seasonal wave regime presented in Figures 26 and 27. The latter diagrams, prepared by Dr. Warren C. Thompson from North Hemisphere wave-hindcast data compiled by National Marine Consultants (1960) at their Station 5, show the frequency of occurrence and relatvie wave power for waves entering the westerly and southerly wave windows shown in Figure 3. The agreement between the annual patterns shown in Figure 5 and Figures 26 and 27 is clear. Southerly Swell due to Southern Hemisphere storms, which has its highest frequency of occurrence in the Northern Hemisphere summer months, is not included in the data; its energy is very small relative to that represented in Figure 27.

As a result of these considerations it appears that the larger westerly waves arriving from the open ocean, with

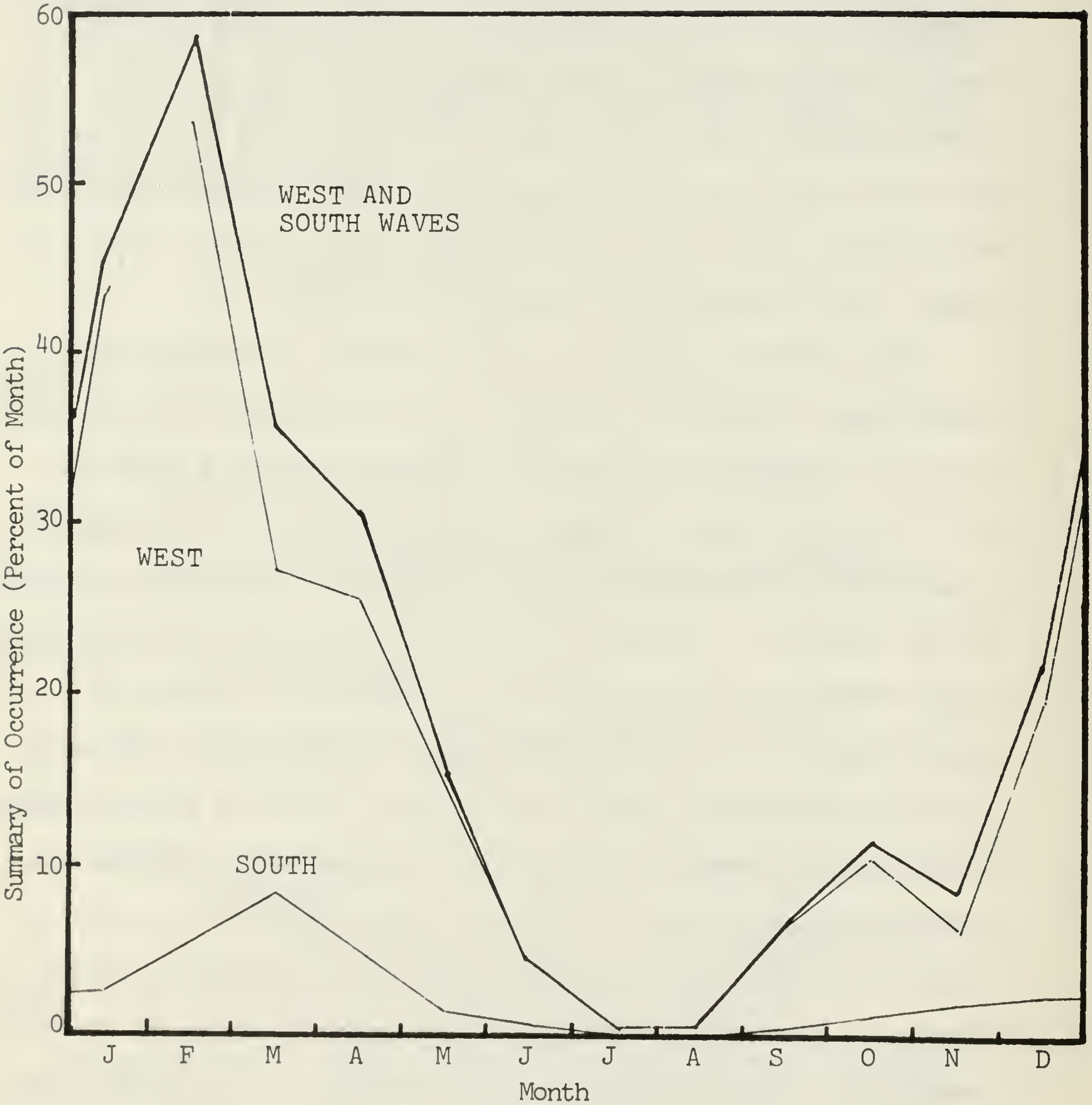

Figure 26: Frequency of Wave Occurrence
(from W.C. Thompson)

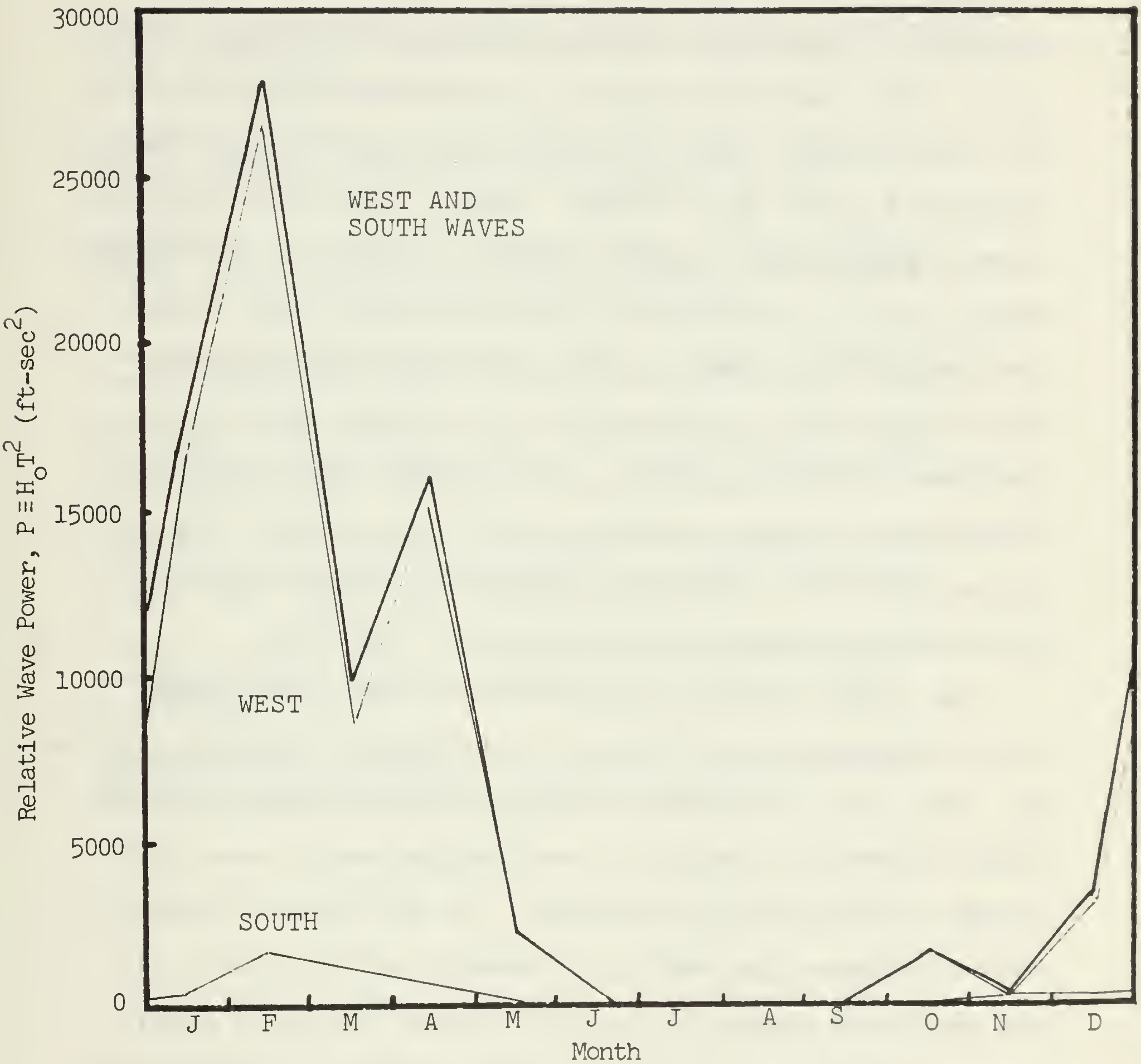

Figure 27: Relative Wave Power
(from W.C. Thompson)

their energy concentrated by convergence, cause sufficient turbulence at the entrance to the Ventura Marina inlet to maintain in suspension the sand supplied by littoral transport. This suspended sediment is subsequently carried into the mouth of the inlet by the same wave action, undoubtedly reinforced by the flood tides. Much of this sand fills the seaward edge of the dredged channel. However, a substantial amount, due to refraction of the penetrating waves around the North Jetty, comes to rest just inside the sheltered lee of the jetty, as witnessed by the higher fill rates in that area (Tables IV and V). At the same time, as the refracted waves travel around the end of the North Jetty and up the inlet they transport sediment as littoral drift depositing it along the north shore of the inlet.

The slopes assumed by the deposited sand also appear to be controlled by the amount of turbulence and wave activity. The inlet is exposed to westerly waves which penetrate along a corridor leading to the spending beach where their energy is effectively dissipated. In this area of maximum wave turbulence the sand fill presents gentle slopes. In the sheltered region of the inlet behind the North Jetty, however, the slope of the advancing sand fill is steep and appears to represent a slip slope at the angle of repose. These different slopes seem to be related to the effectiveness of the waves in stirring the deeper parts of the channel.

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5. National Ocean Survey, Department of Commerce, Tidal Bench Marks, California, Part II, Port Hueneme (10/2/62) and Santa Barbara (6/25/68) [unpublished].

6. National Ocean Survey, Department of Commerce. Tide Tables for the West Coast, North and South America. Years 1965, 1966, 1967, 1968, 1969.

7. O'Brien, M.P., 1931. Estuary Tidal Prisms Related to Entrance Areas. Civil Engineering, v. 1, No. 8, p. 738-739.

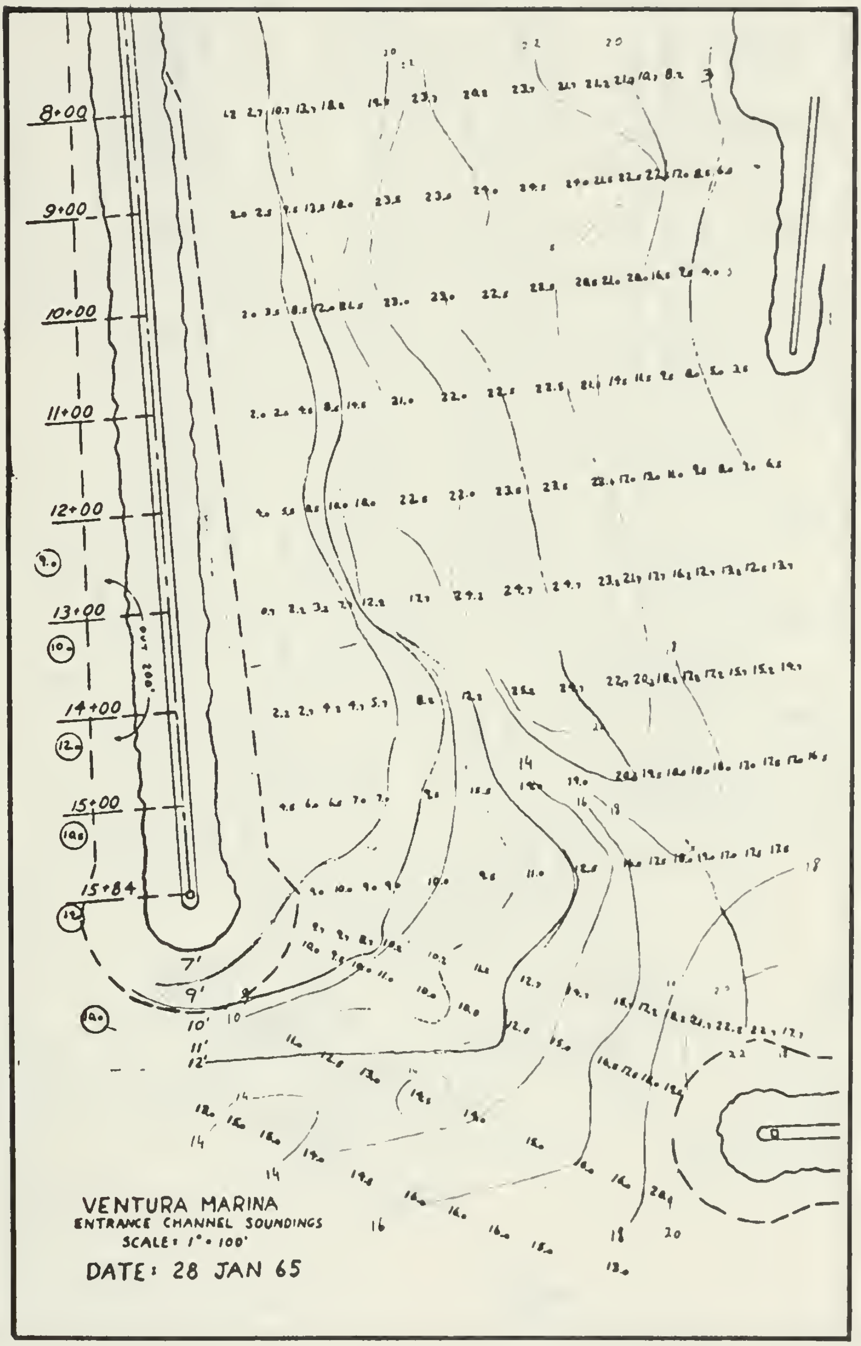
8. Oceanographic Services, Inc., 1965. Oceanographic Study of Ventura Marina - Phases I and II.

APPENDIX

SOUNDING SURVEYS OF VENTURA MARINA

January 1965 through January 1969

The sounding surveys reduced to 50% and arranged in chronological order, are in the form of working charts. They were drawn by the Ventura Port District and were contoured at a 2 foot interval by the author.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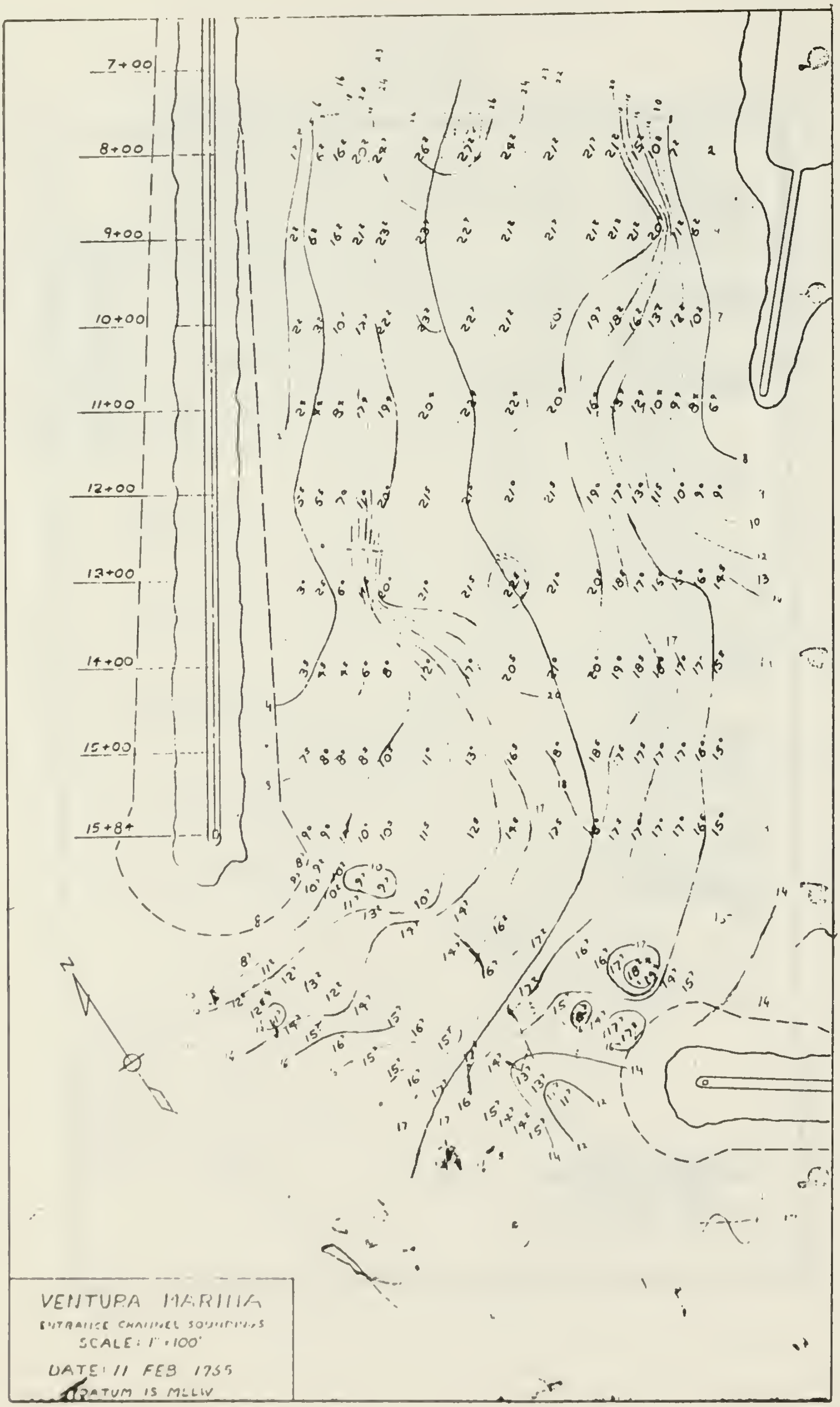
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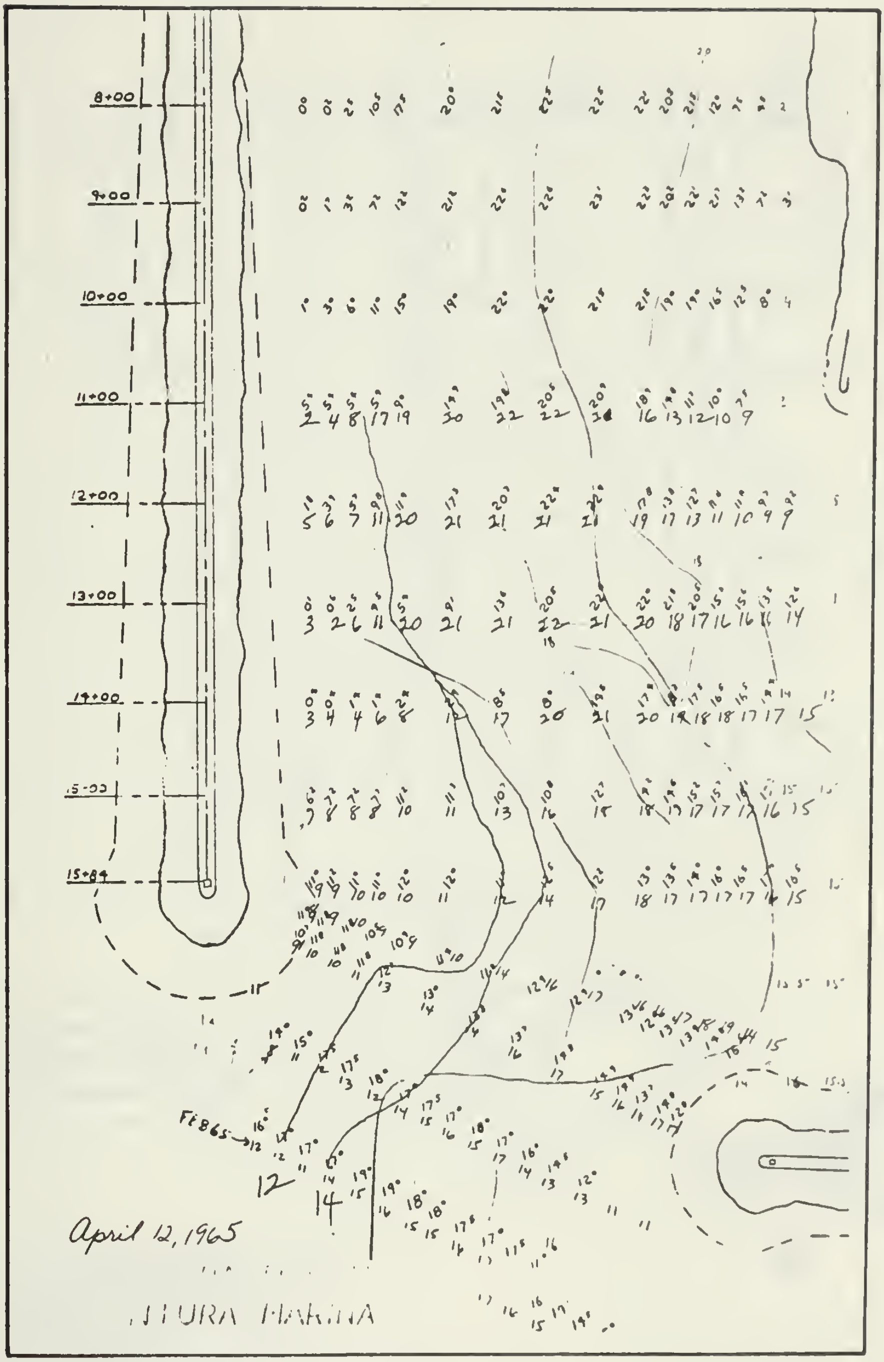
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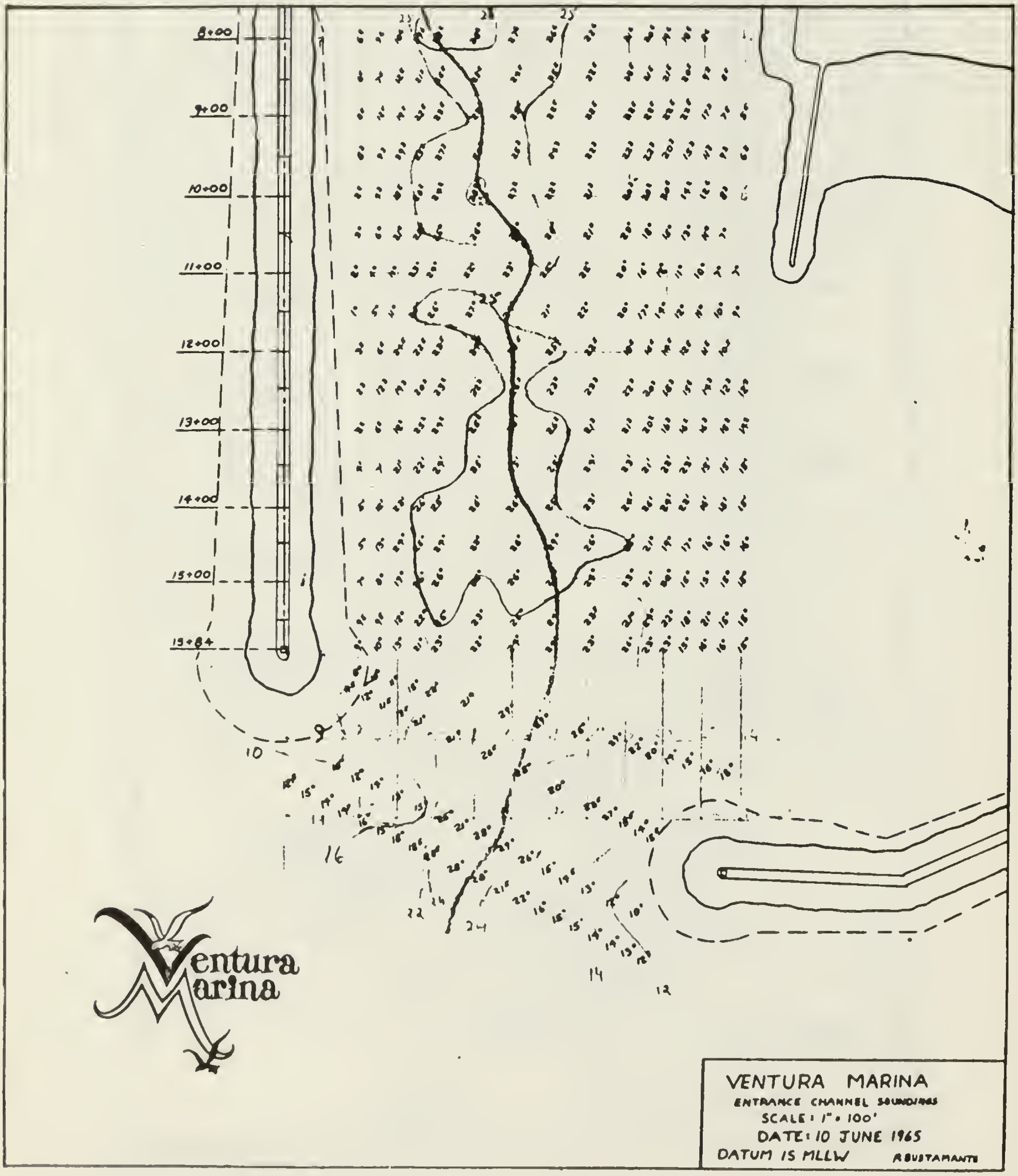
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Ventura Marina
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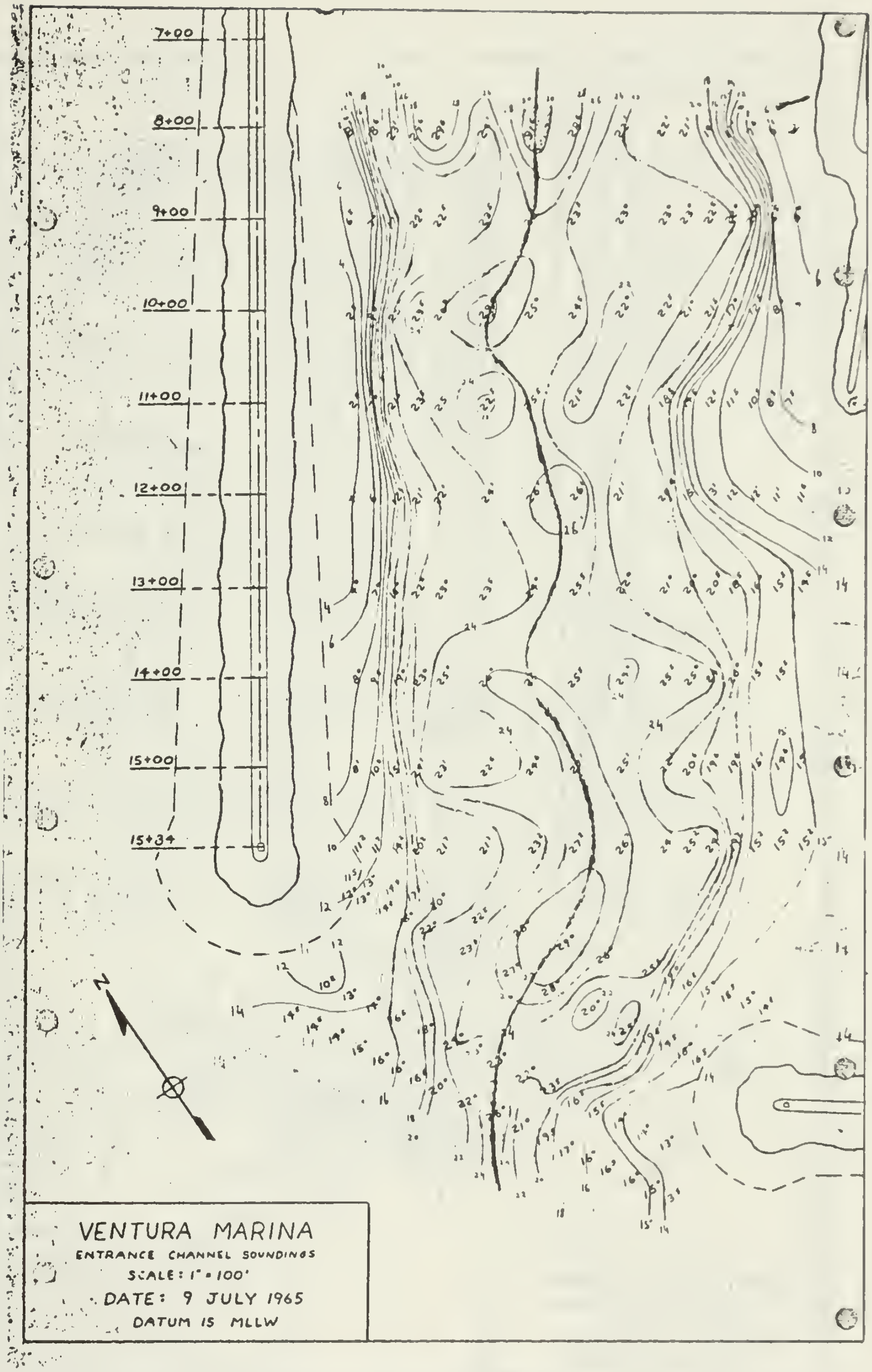
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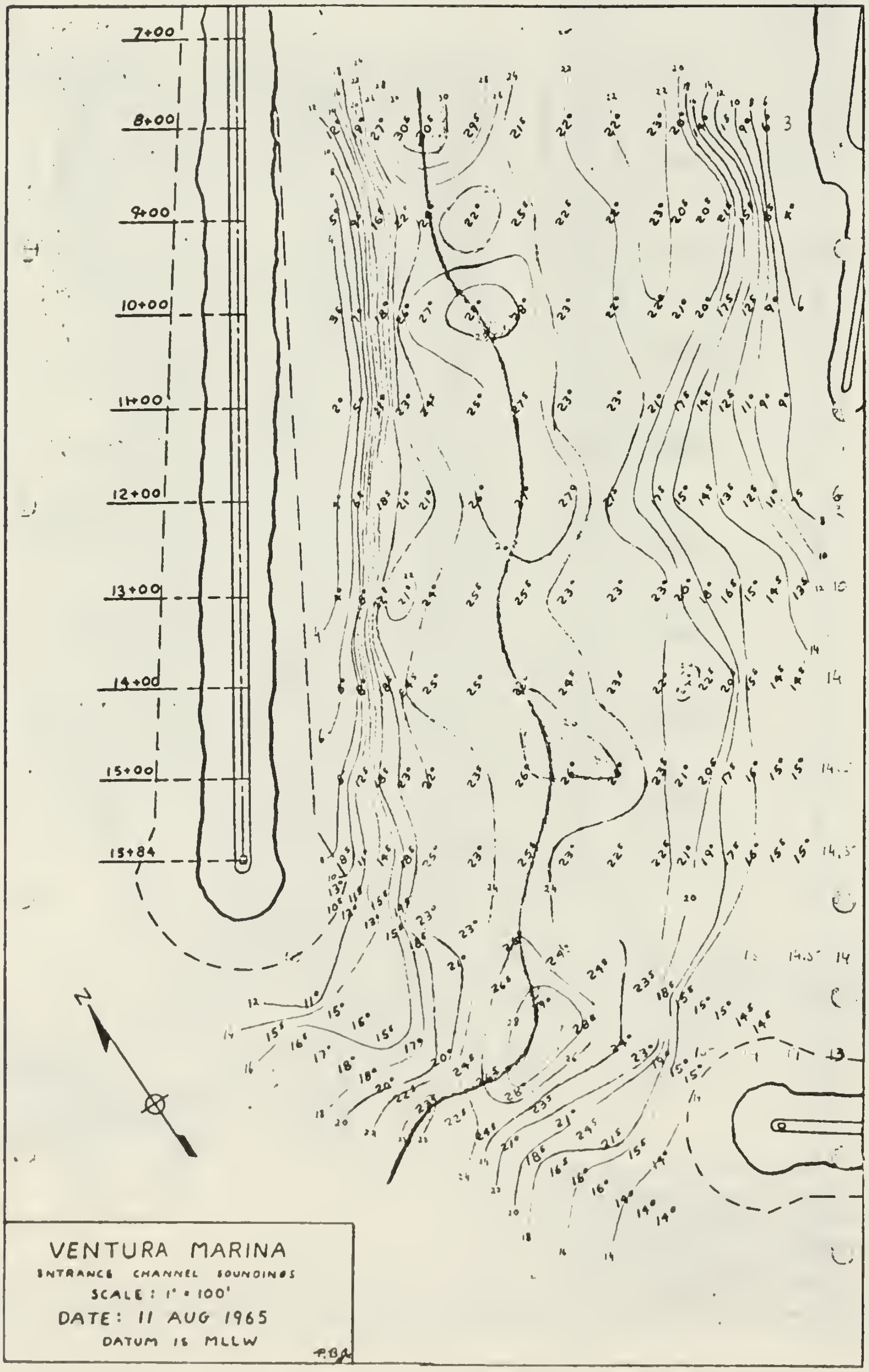
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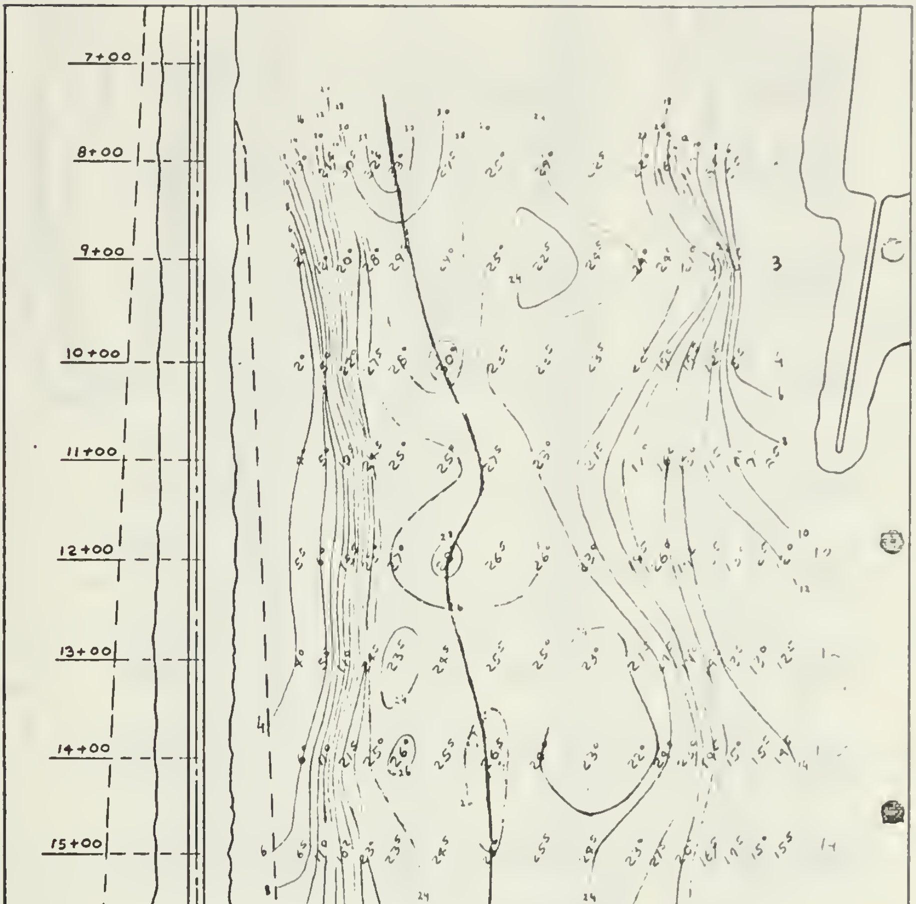
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DATE: 10 SEPT 1965
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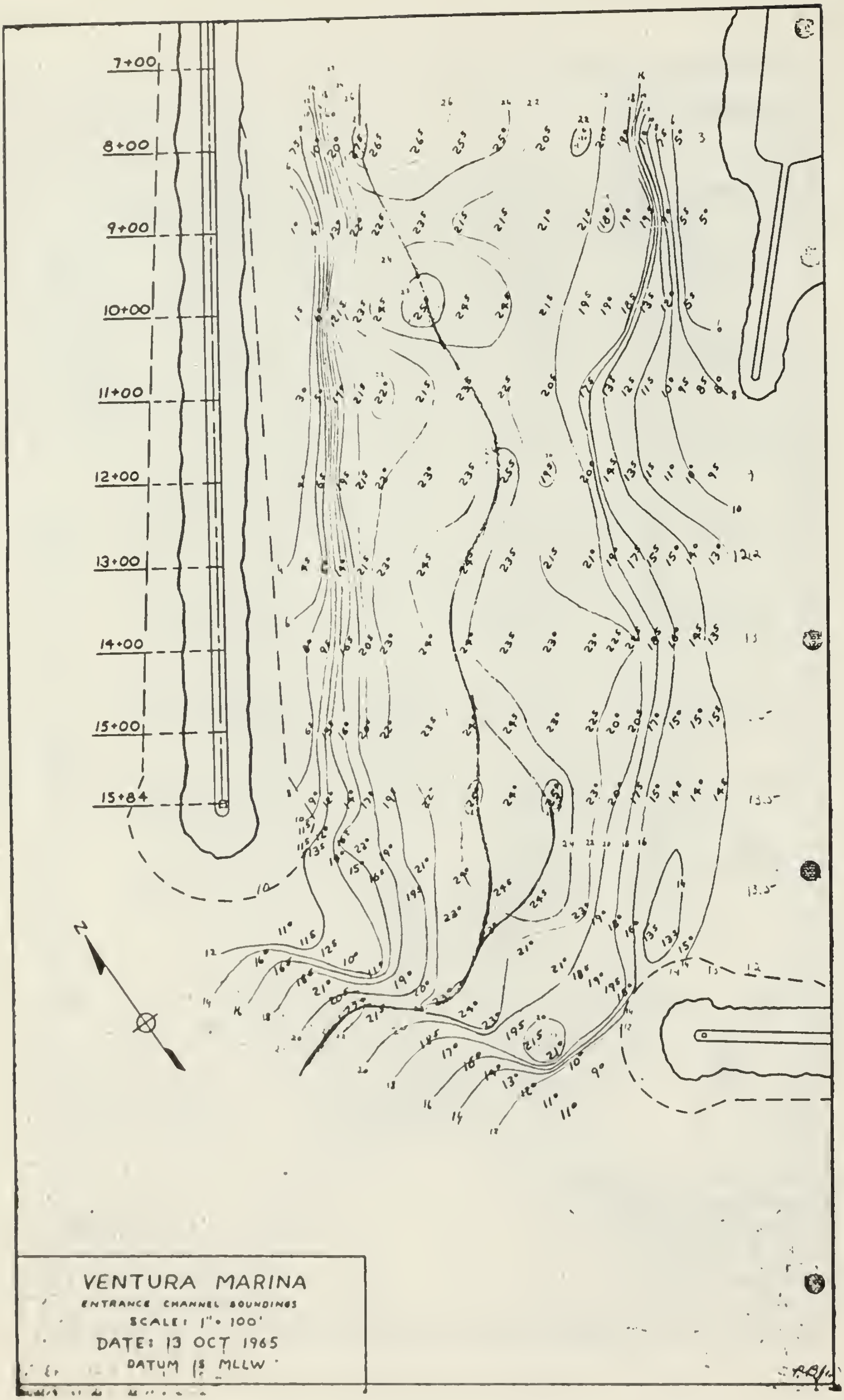
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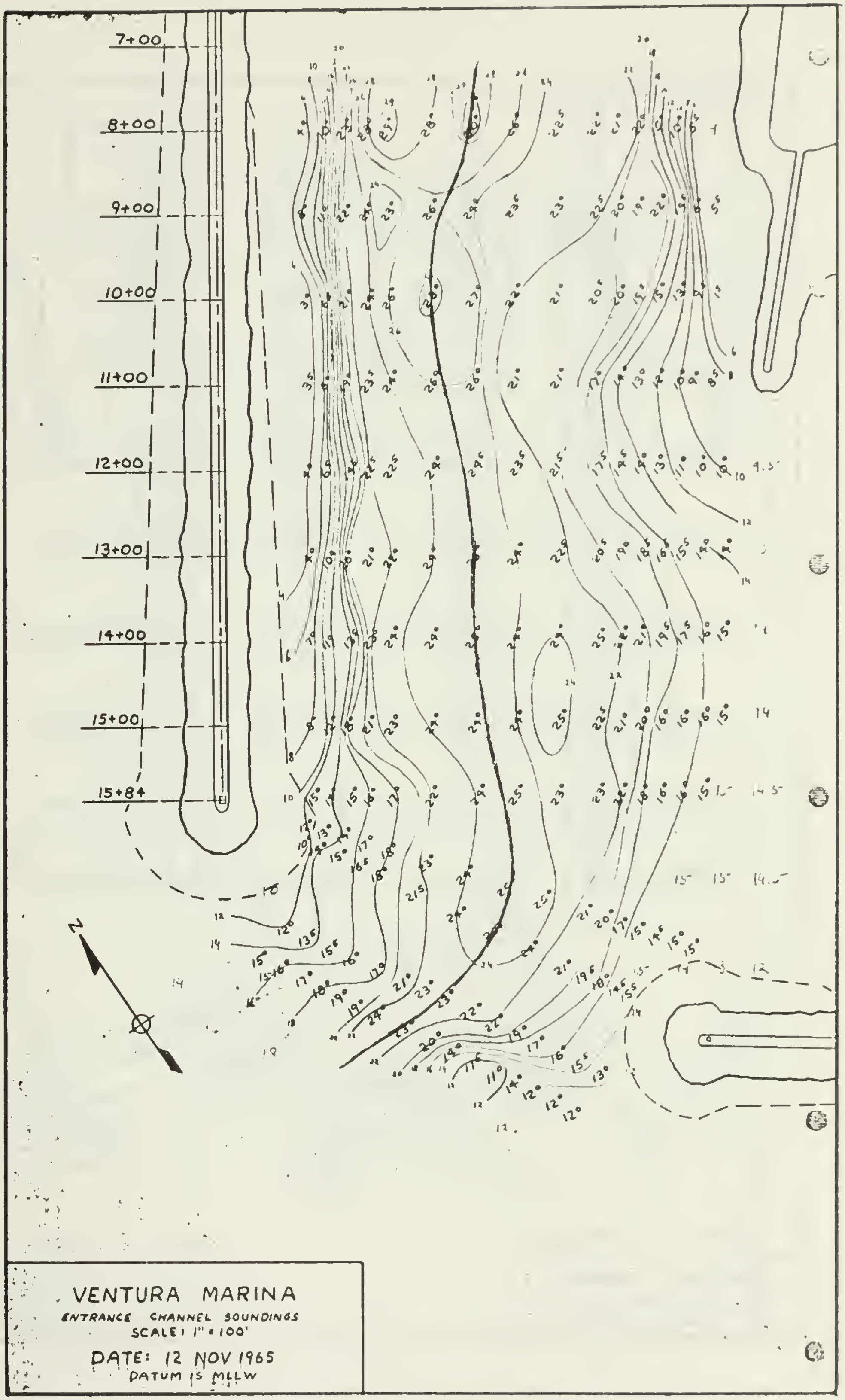
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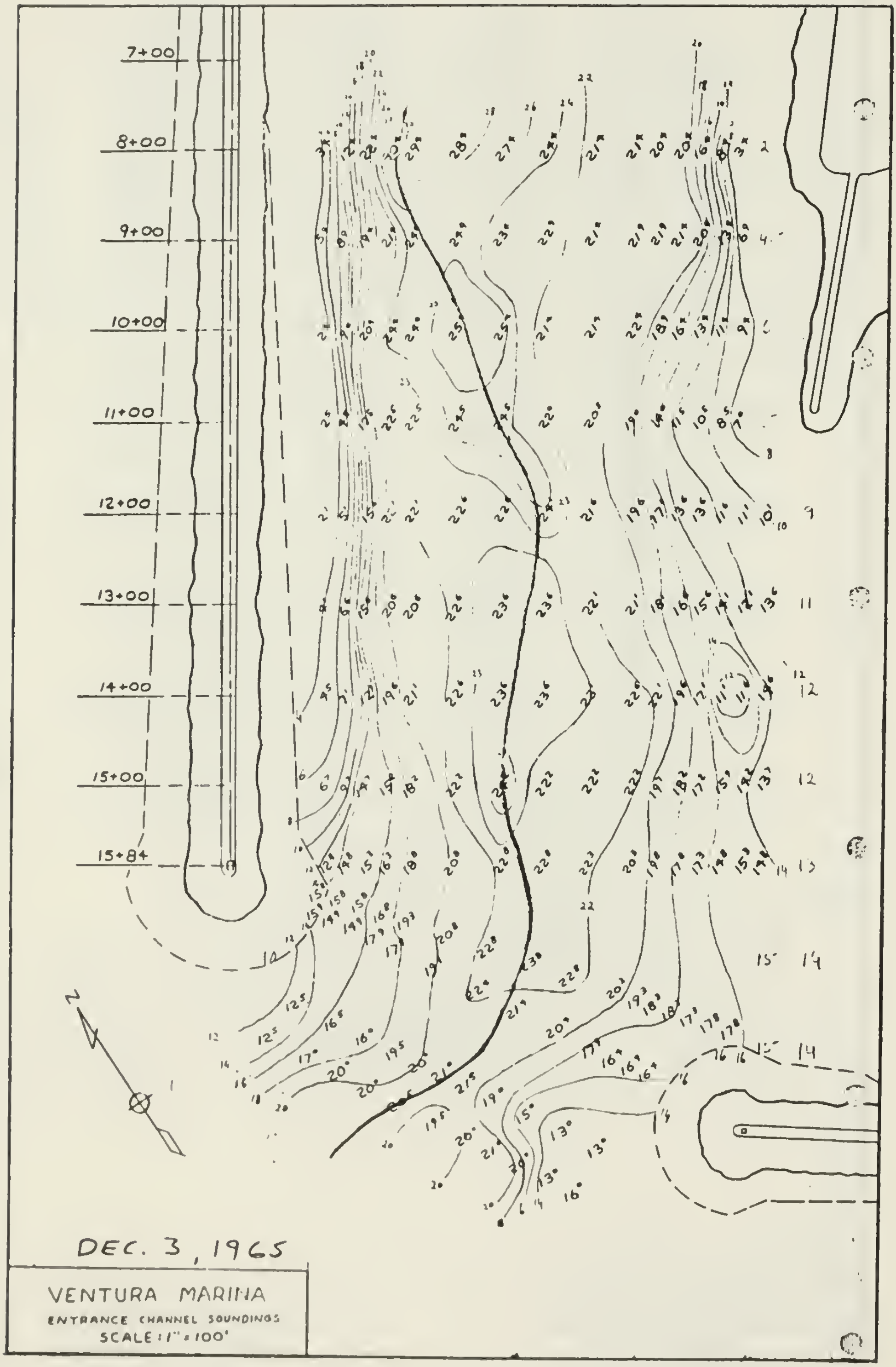
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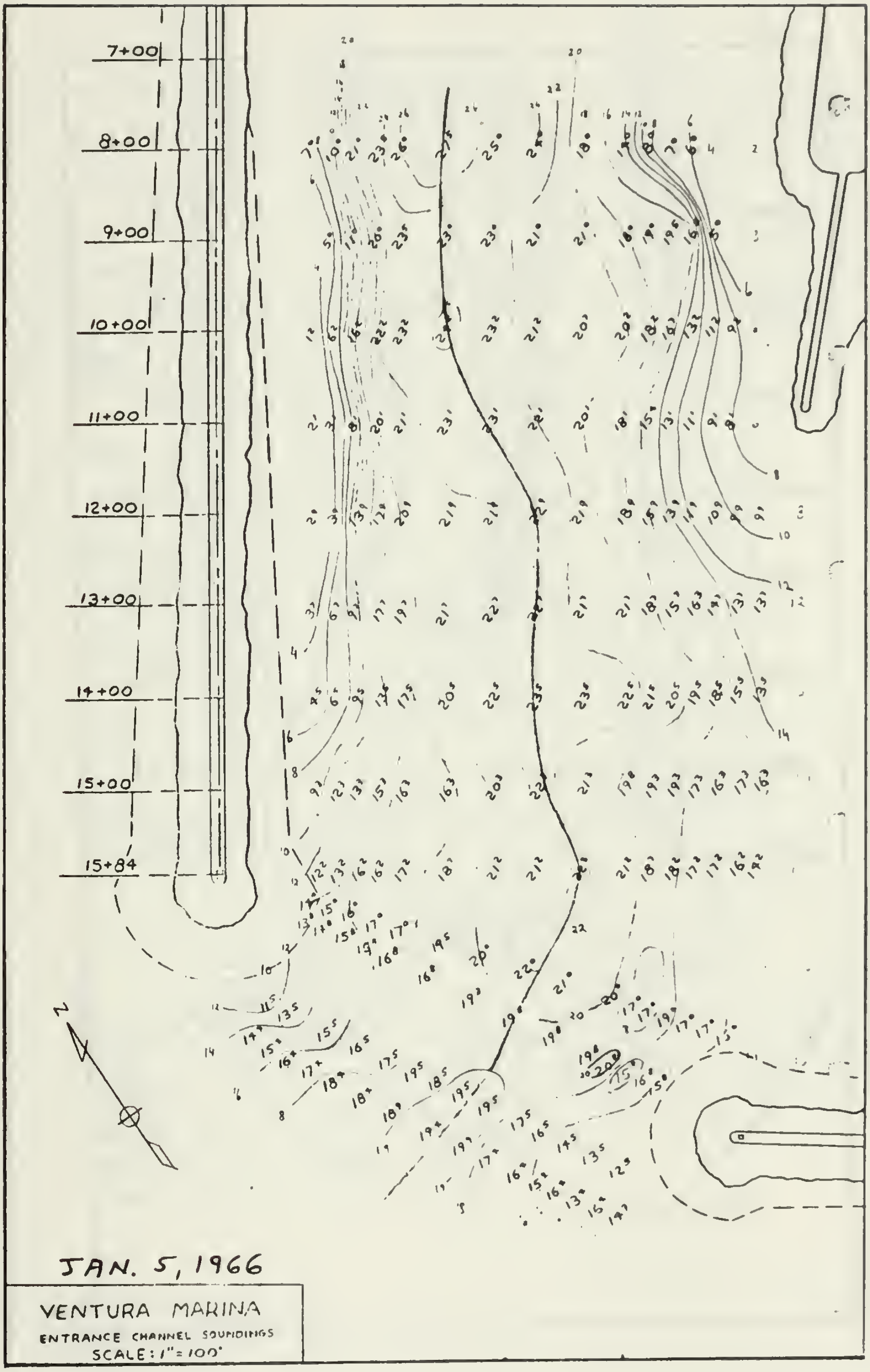
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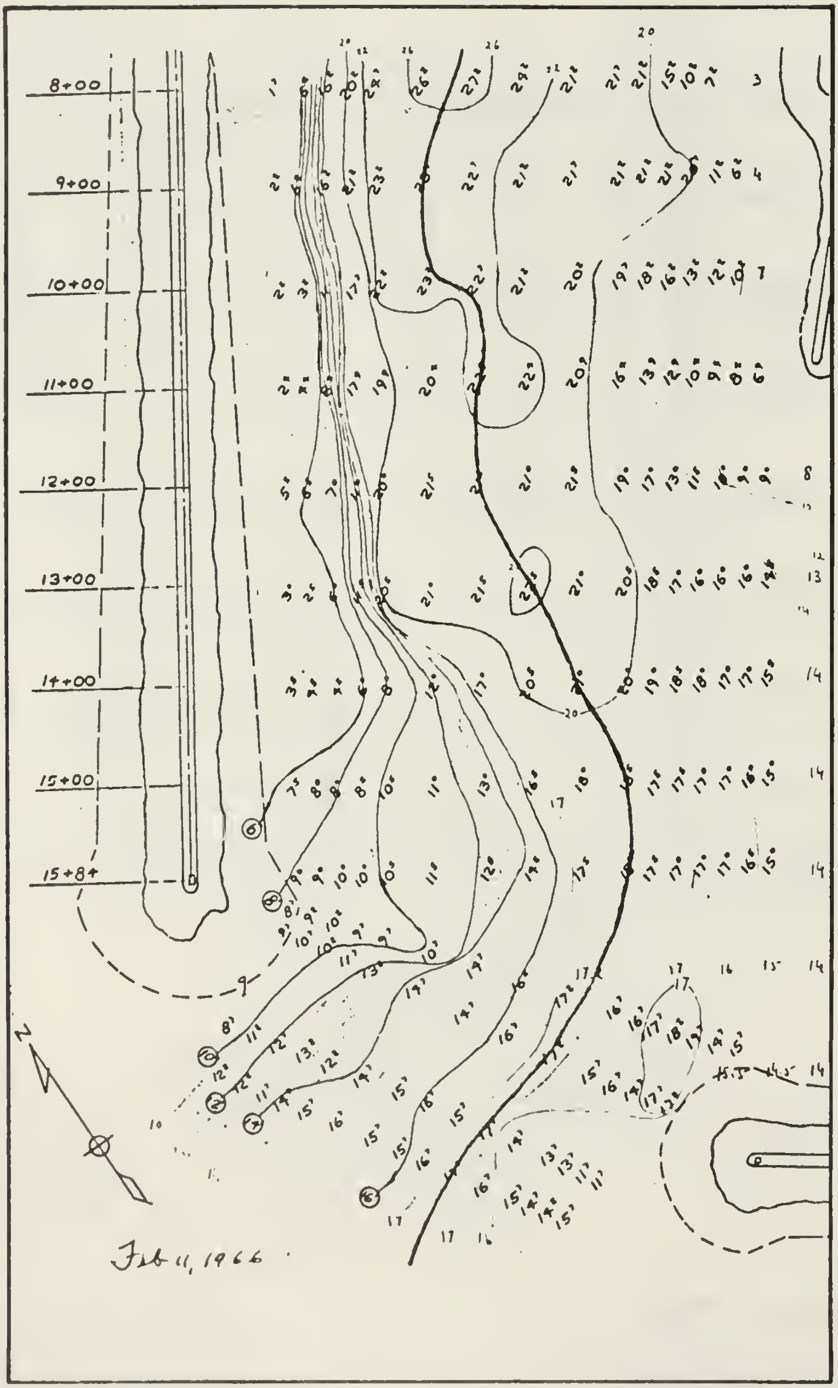
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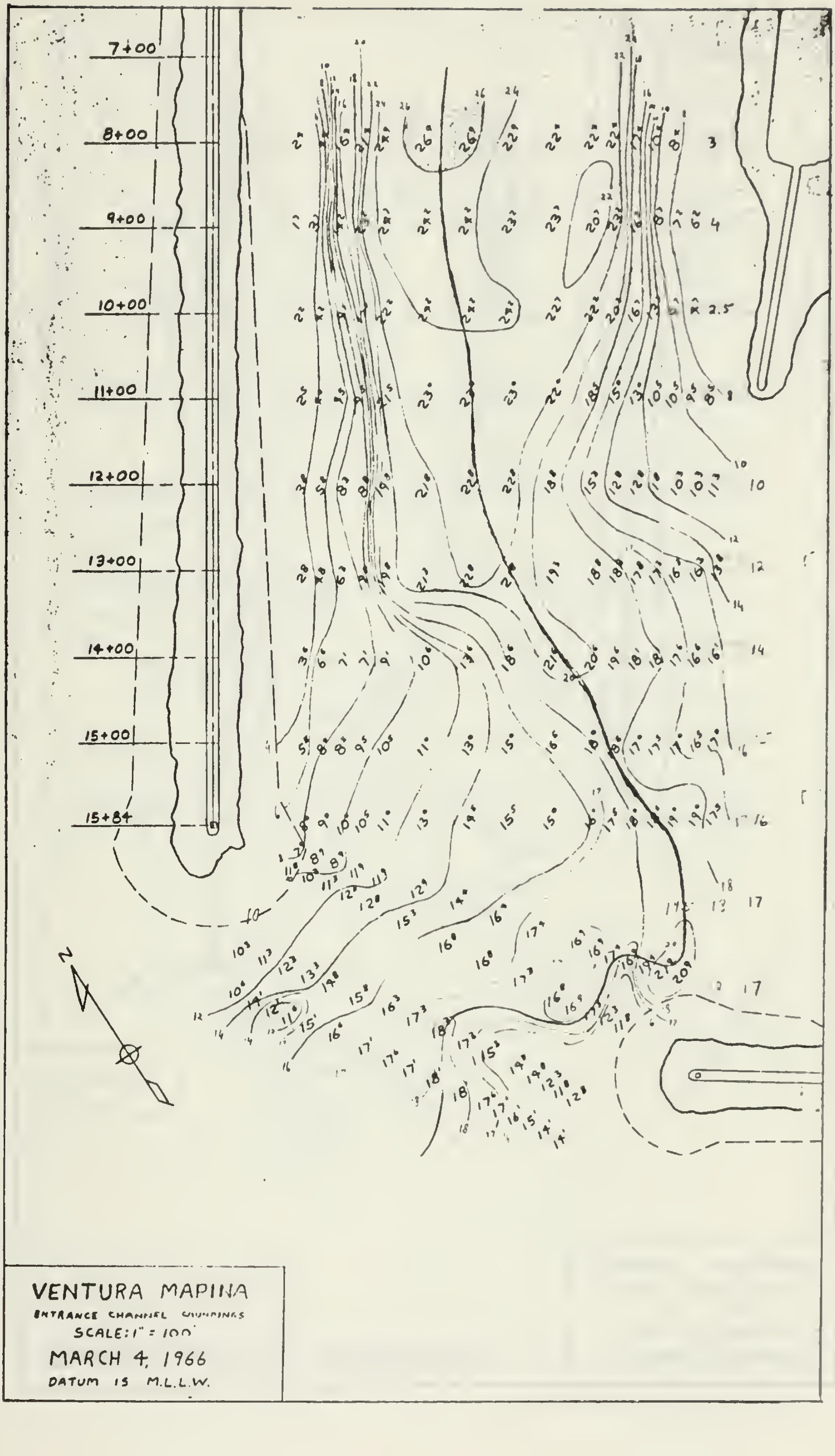
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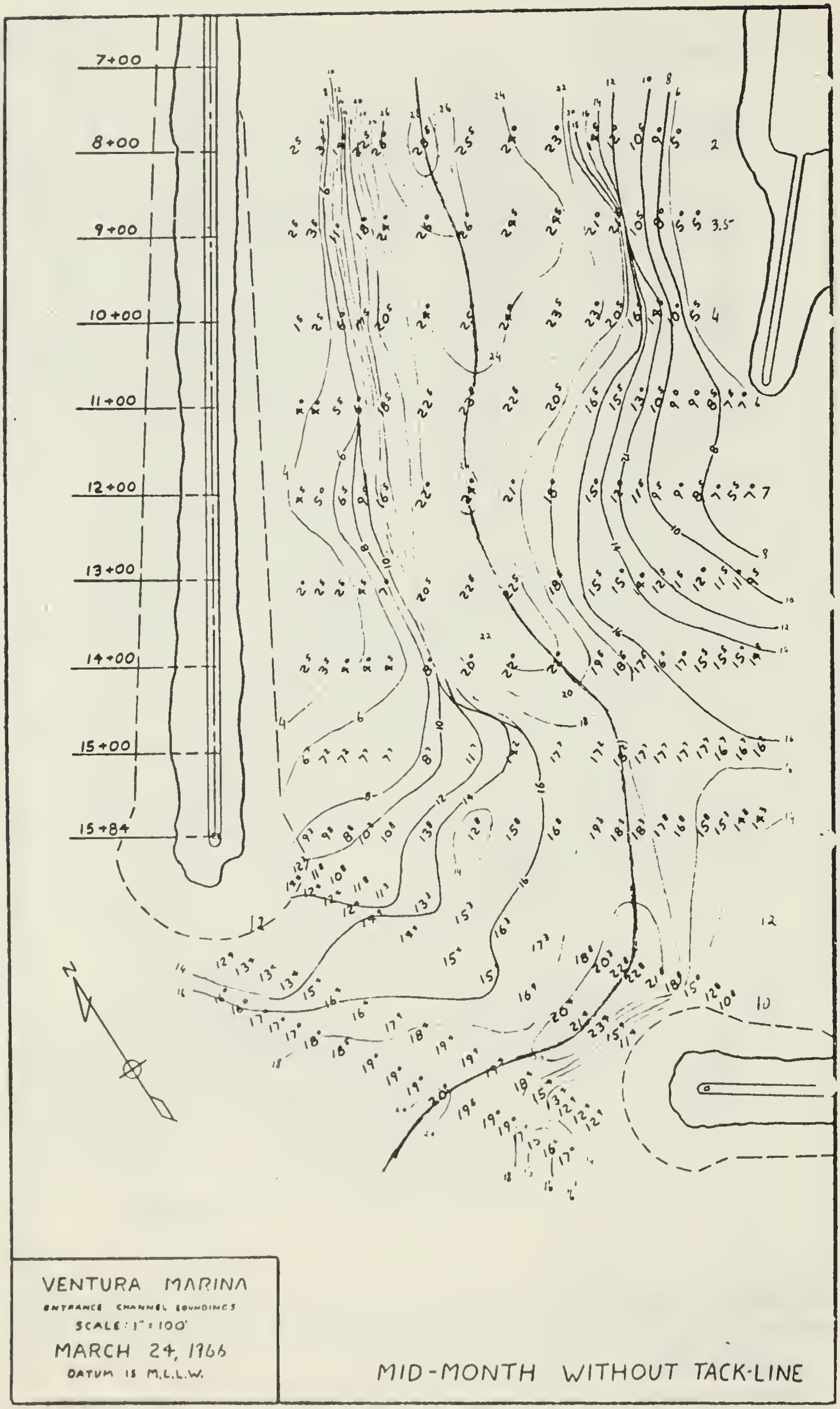
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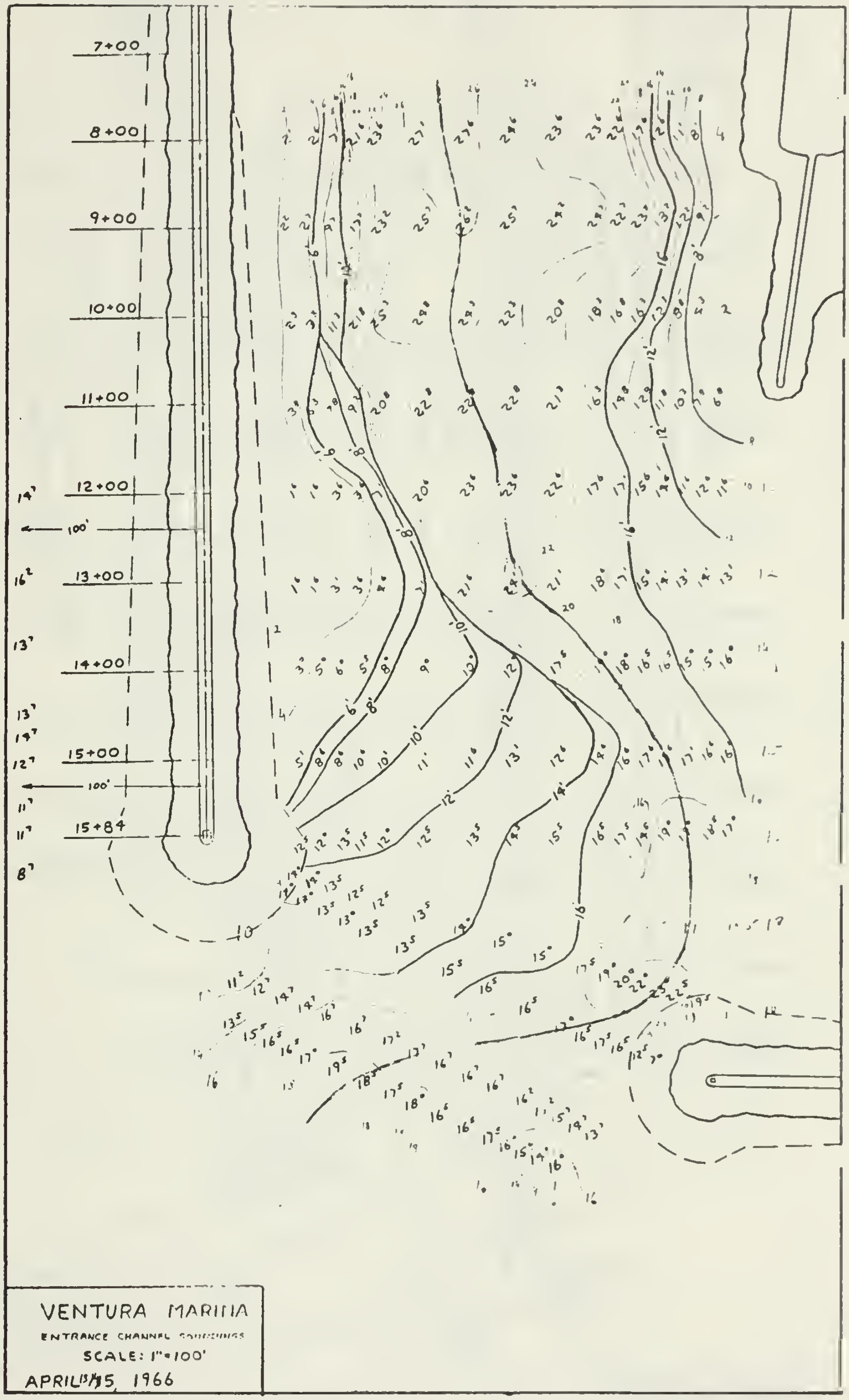

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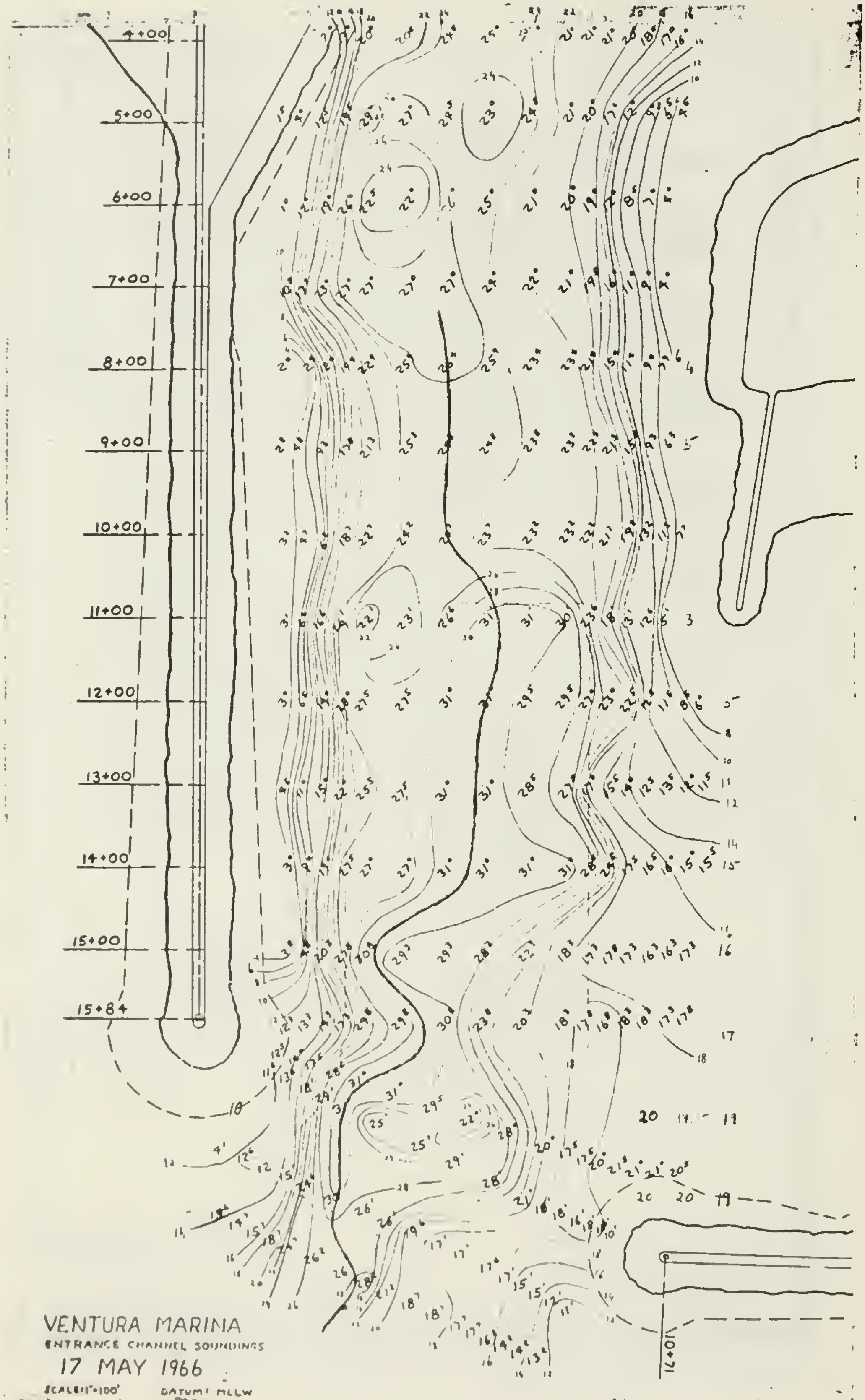
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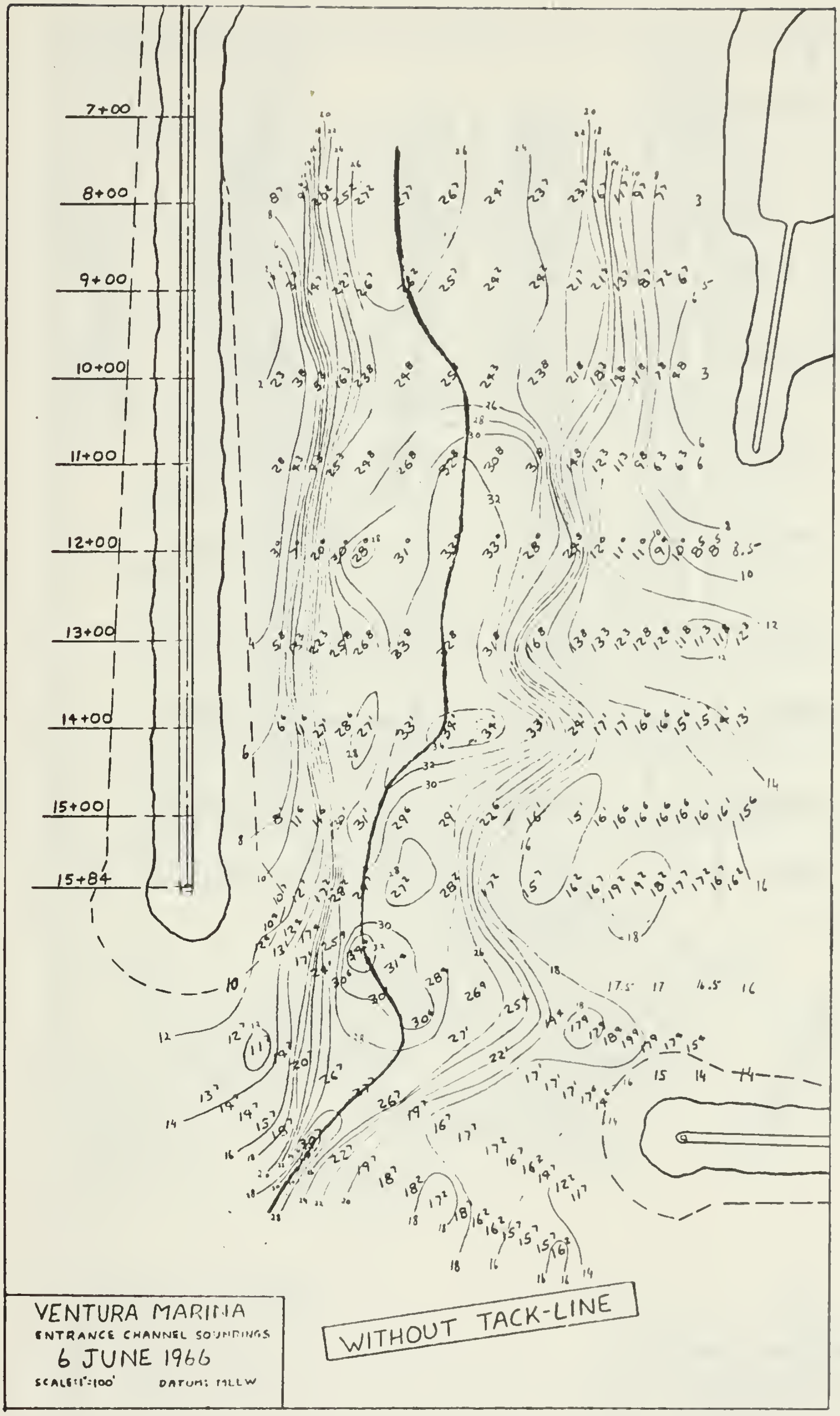
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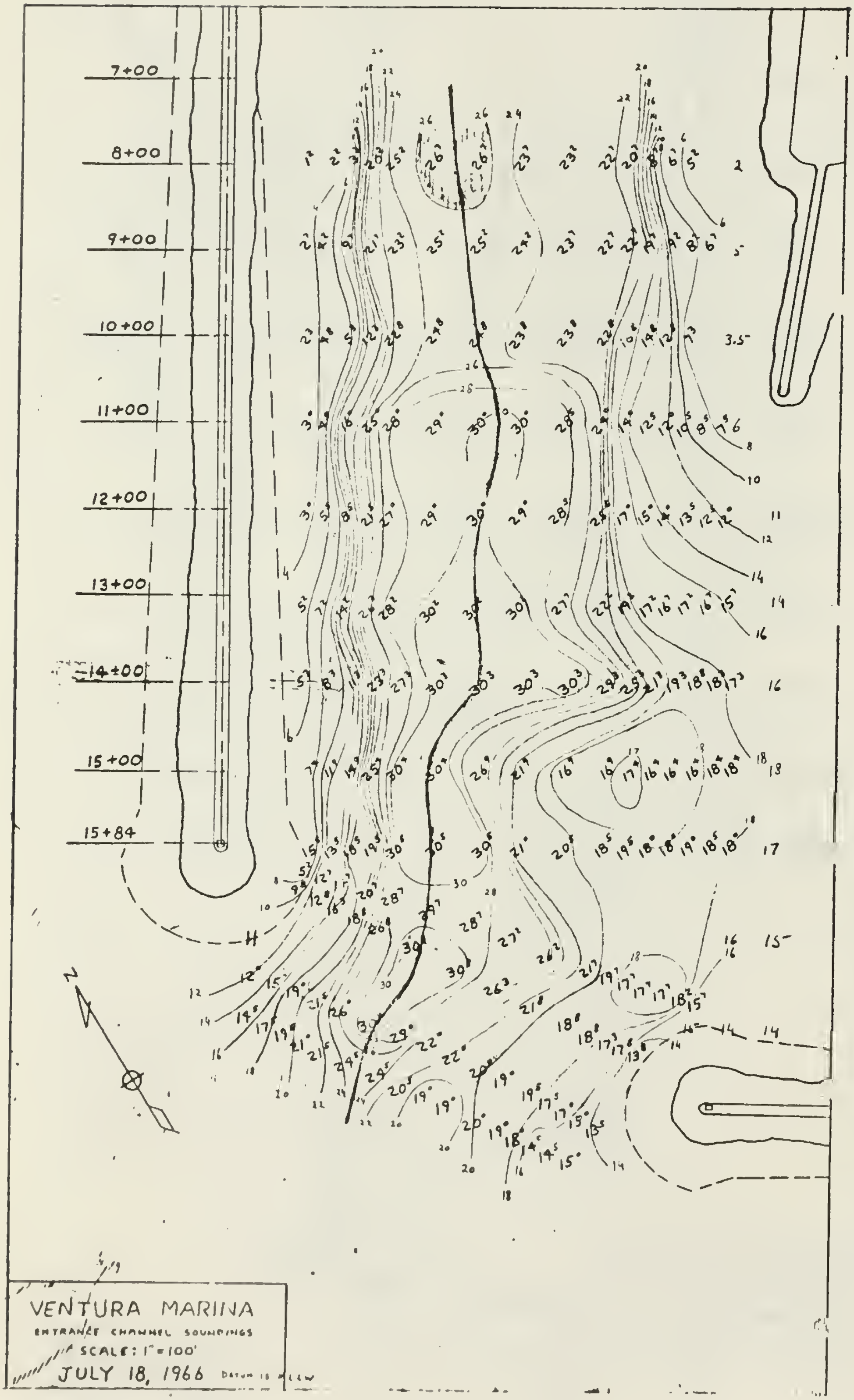
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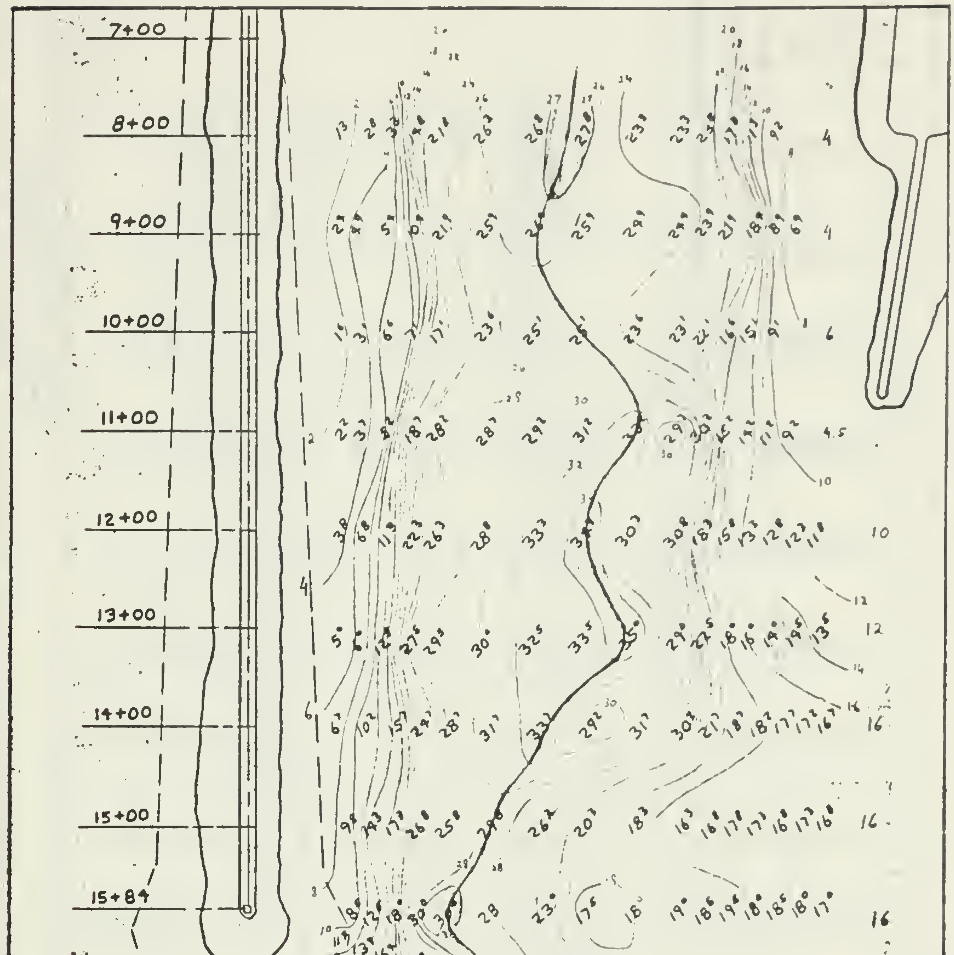
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
JULY 18, 1966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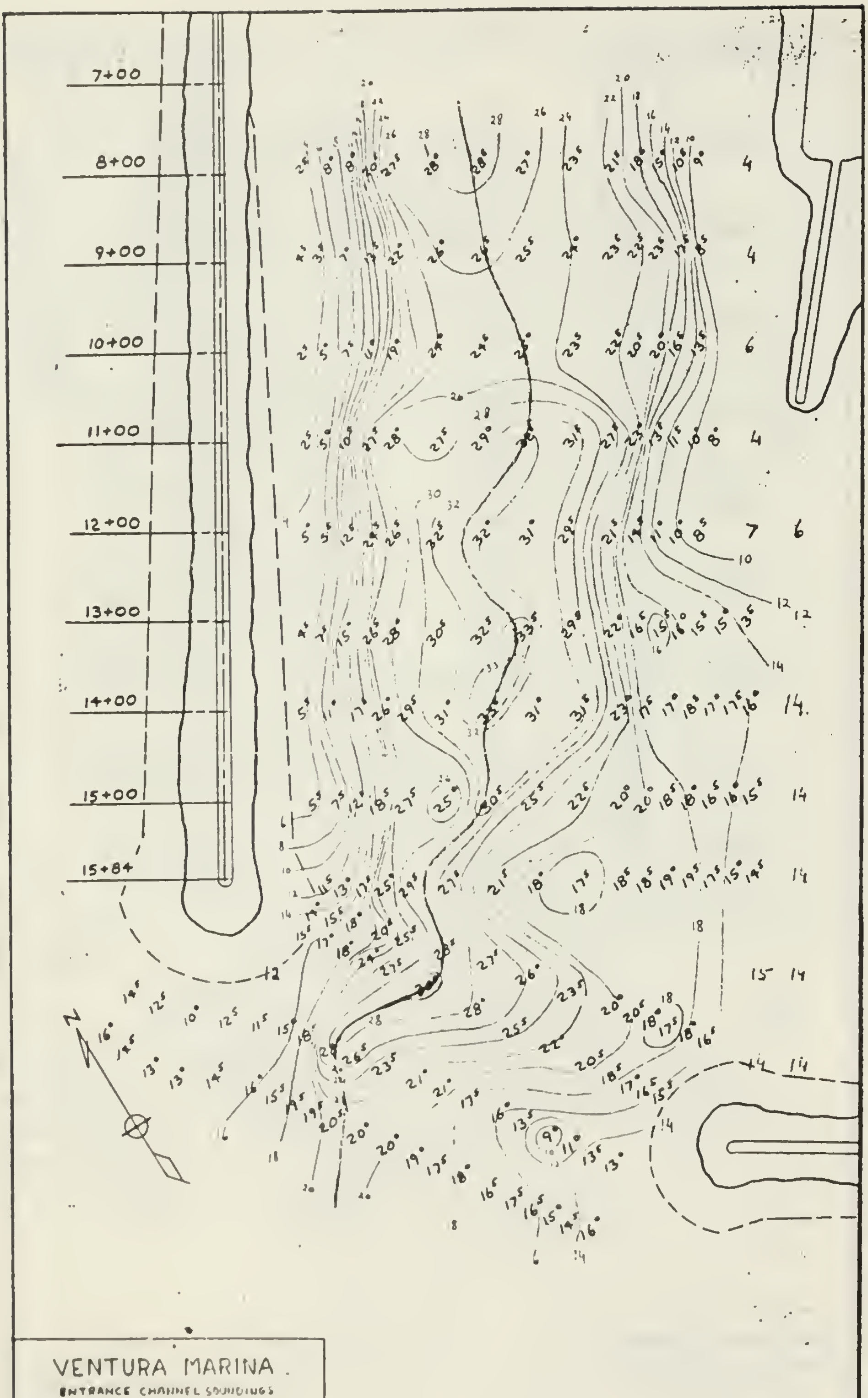
VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
AUG. 19, 1966
DATUM IS M.L.L.W.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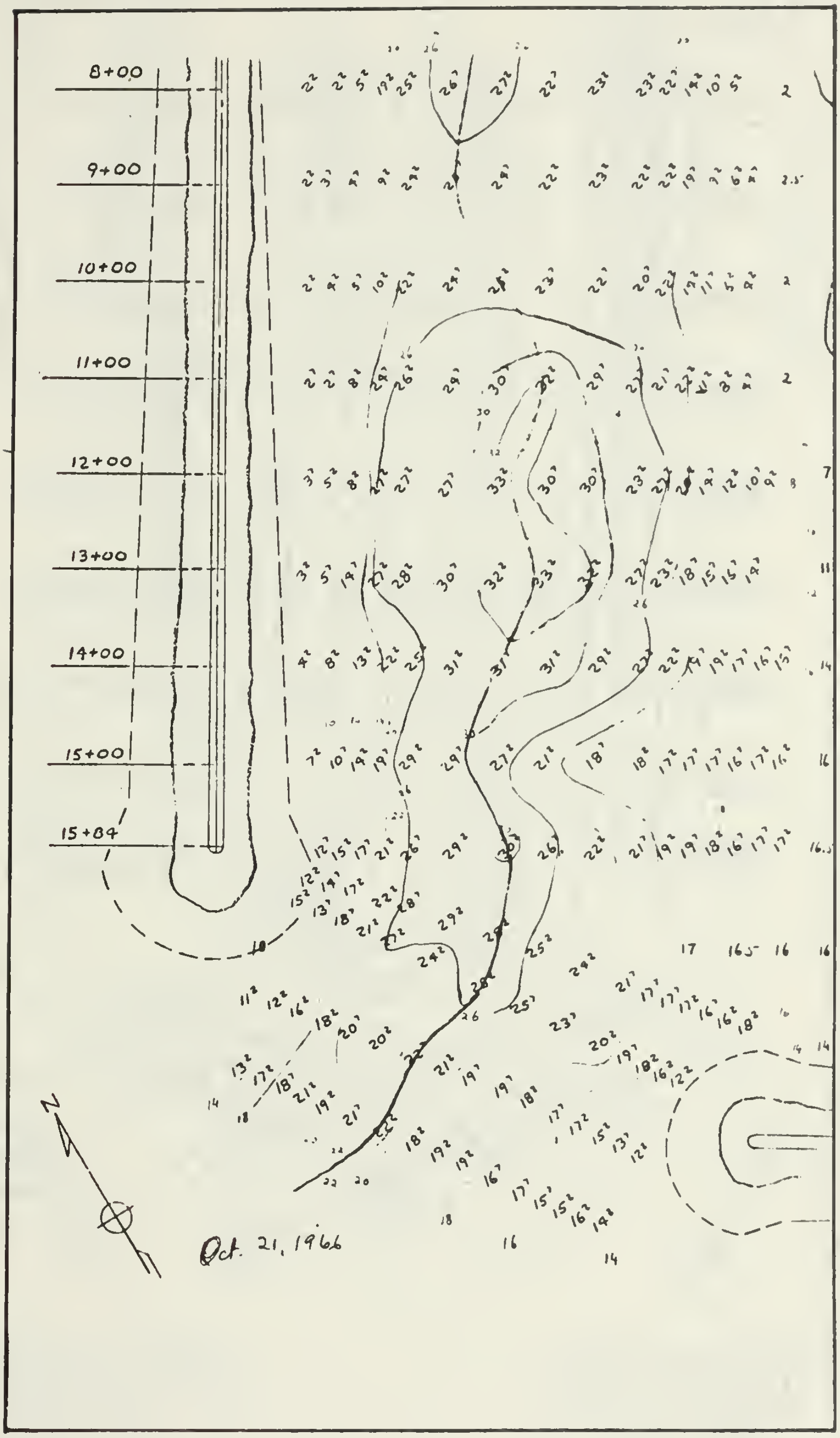
SCALE 1" = 100'
SEPT. 21, 1966
DATUM IS M.L.L.W.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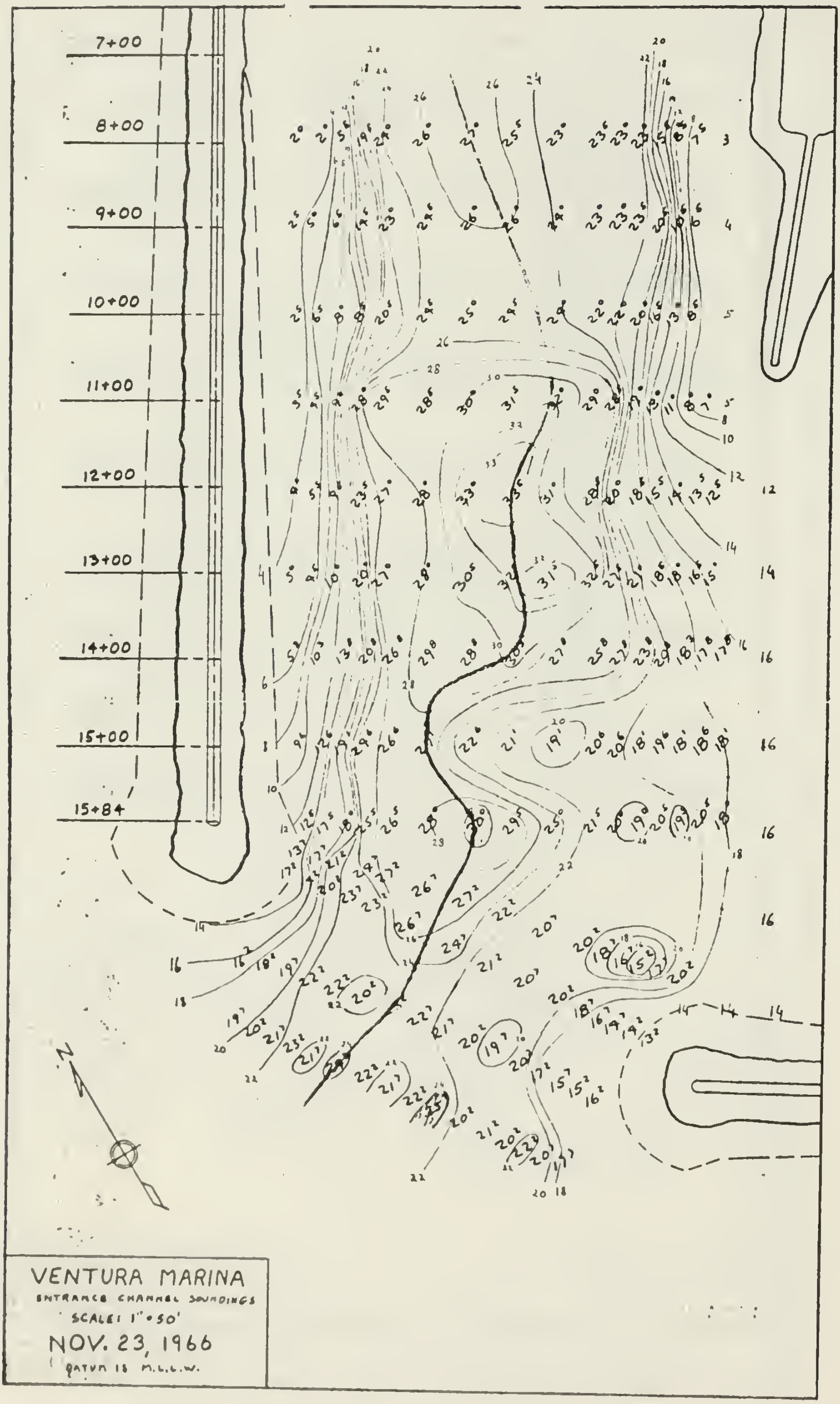
Oct. 21, 1966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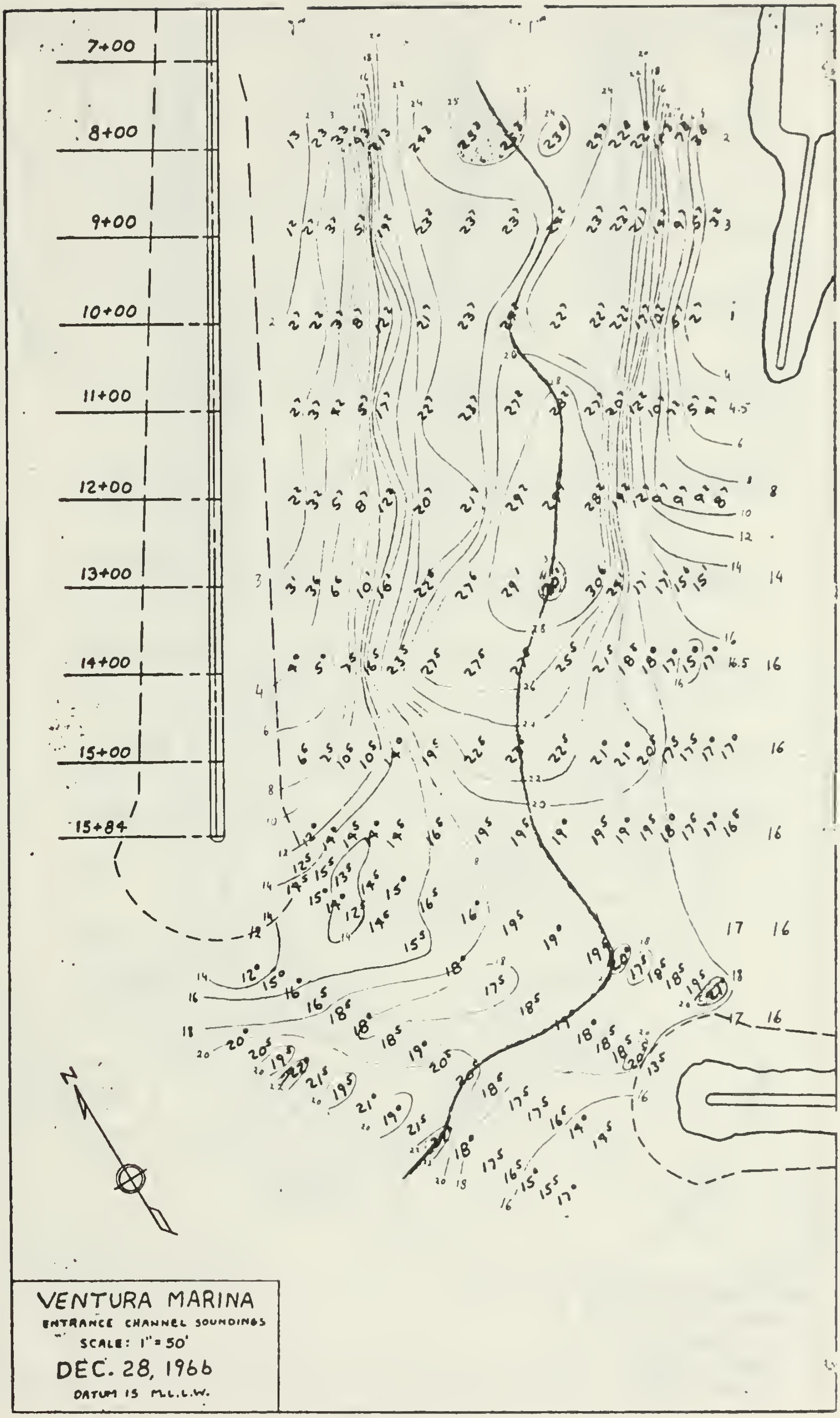
VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1"=50'
NOV. 23, 1966
DATUM IS M.L.L.W.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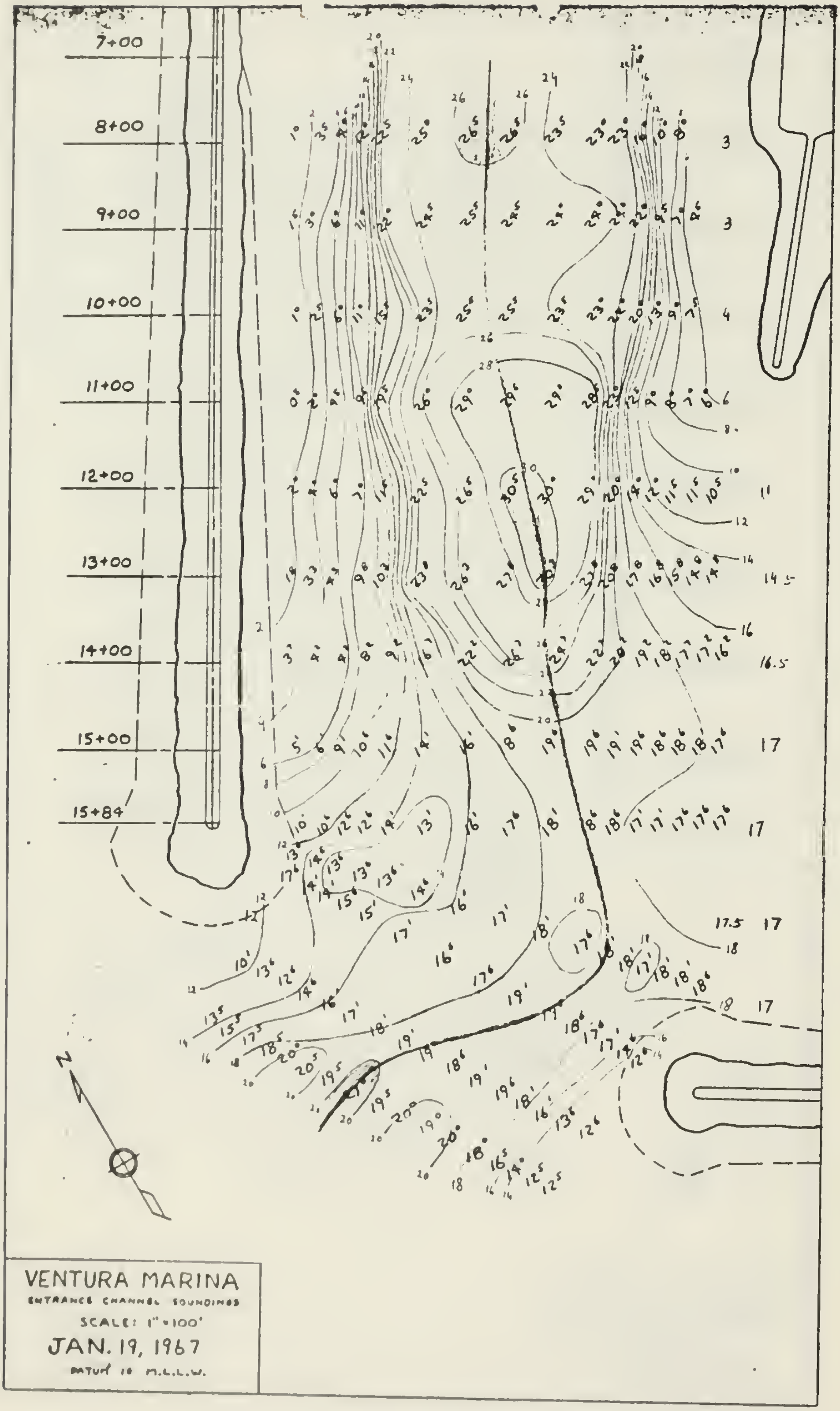
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 50'
DEC. 28, 1966
DATUM IS M.L.L.W.


VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
JAN. 19, 1967
DATUM IS M.L.L.W.
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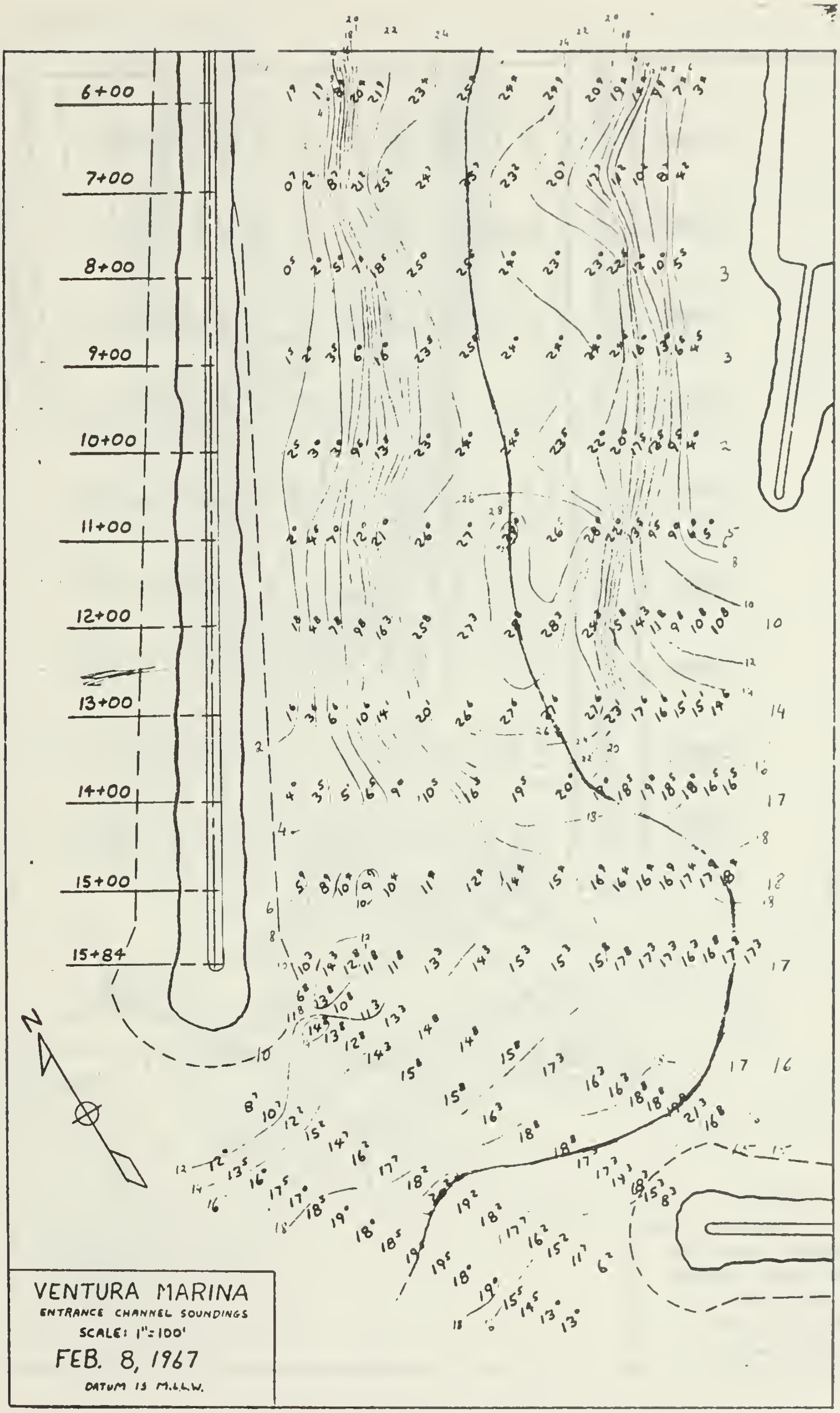
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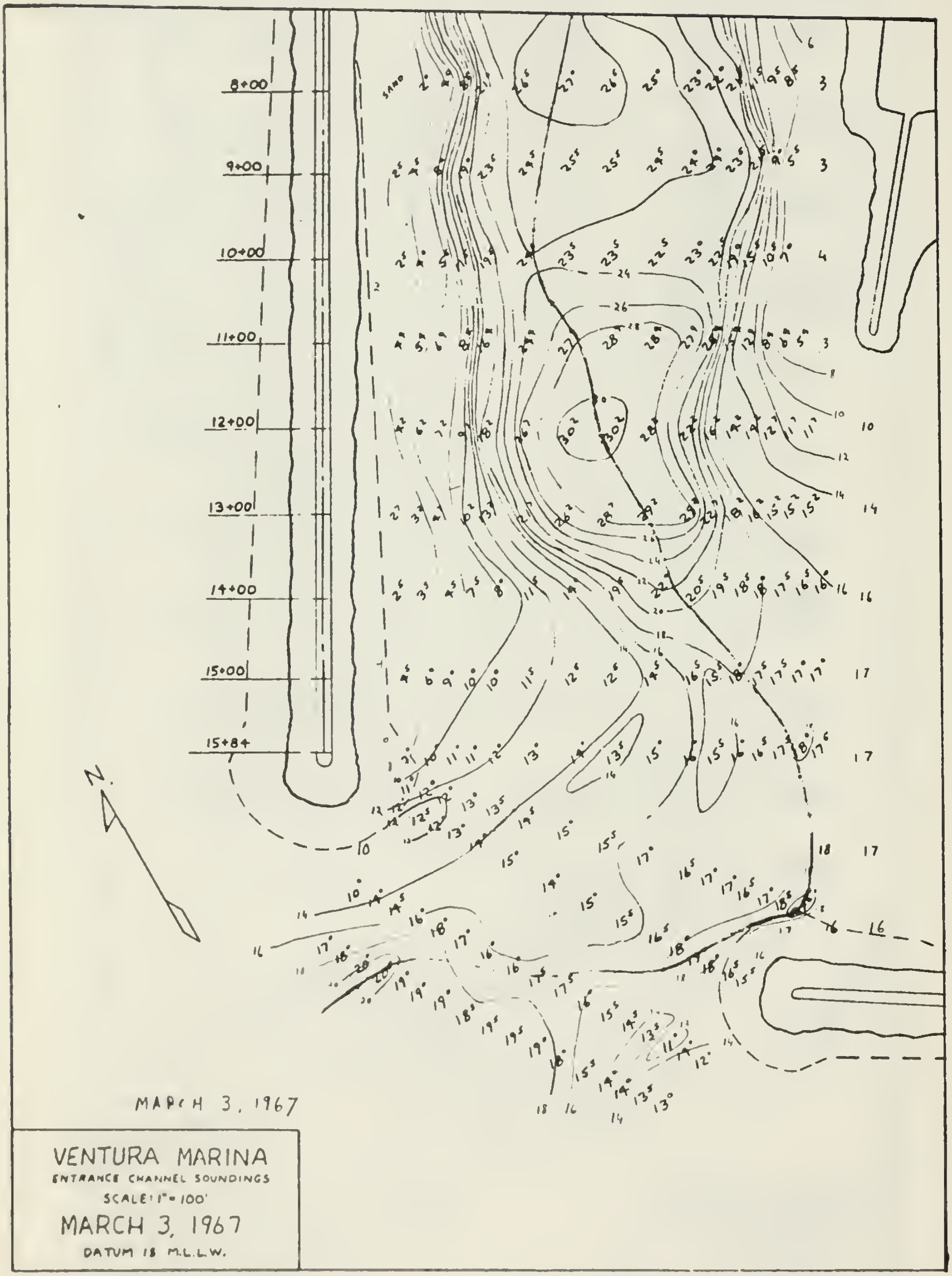
VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1"=100'
FEB. 8, 1967
DATUM IS M.L.L.W.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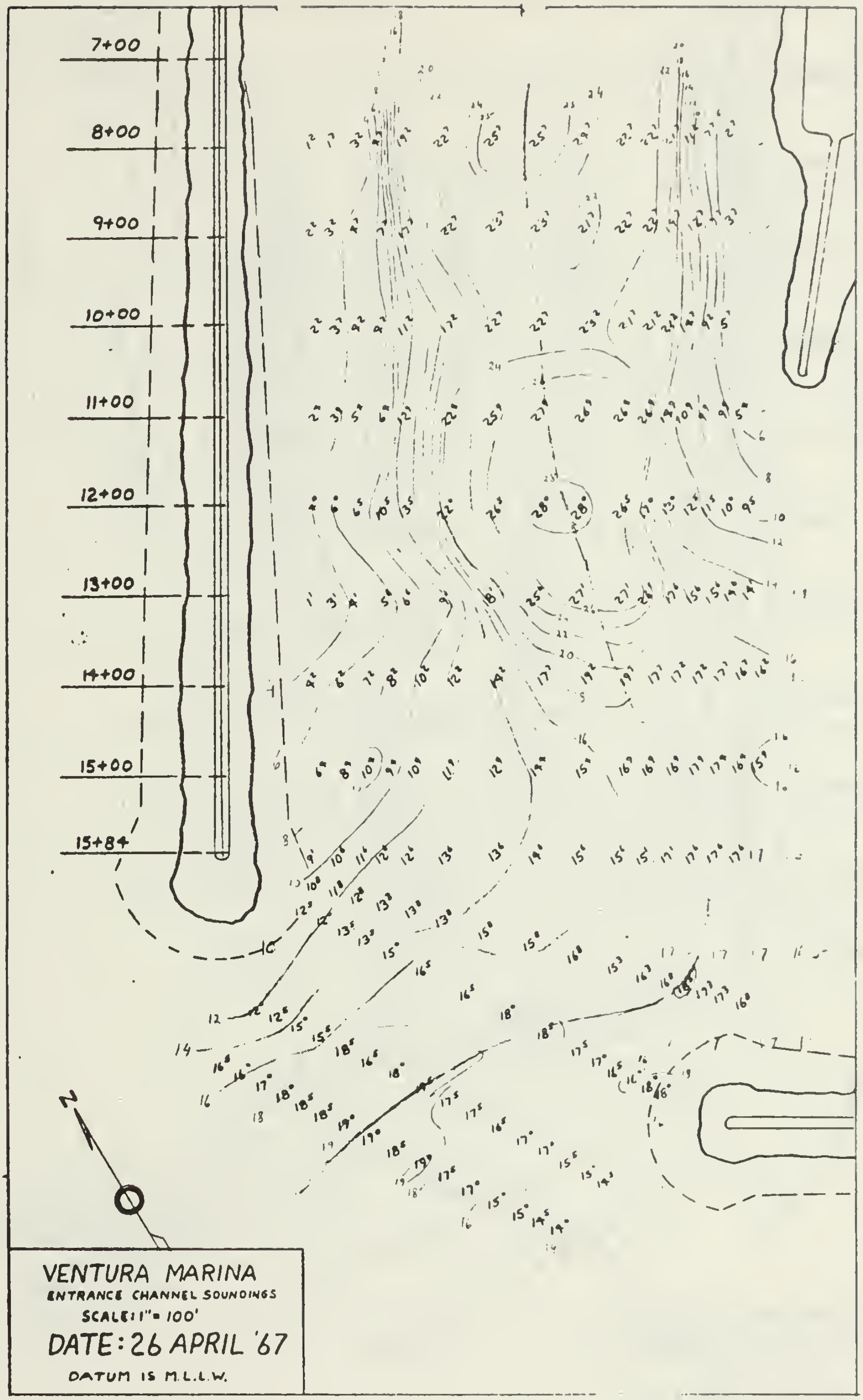
MARCH 3, 1967
VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
MARCH 3, 1967
DATUM IS M.L.L.W.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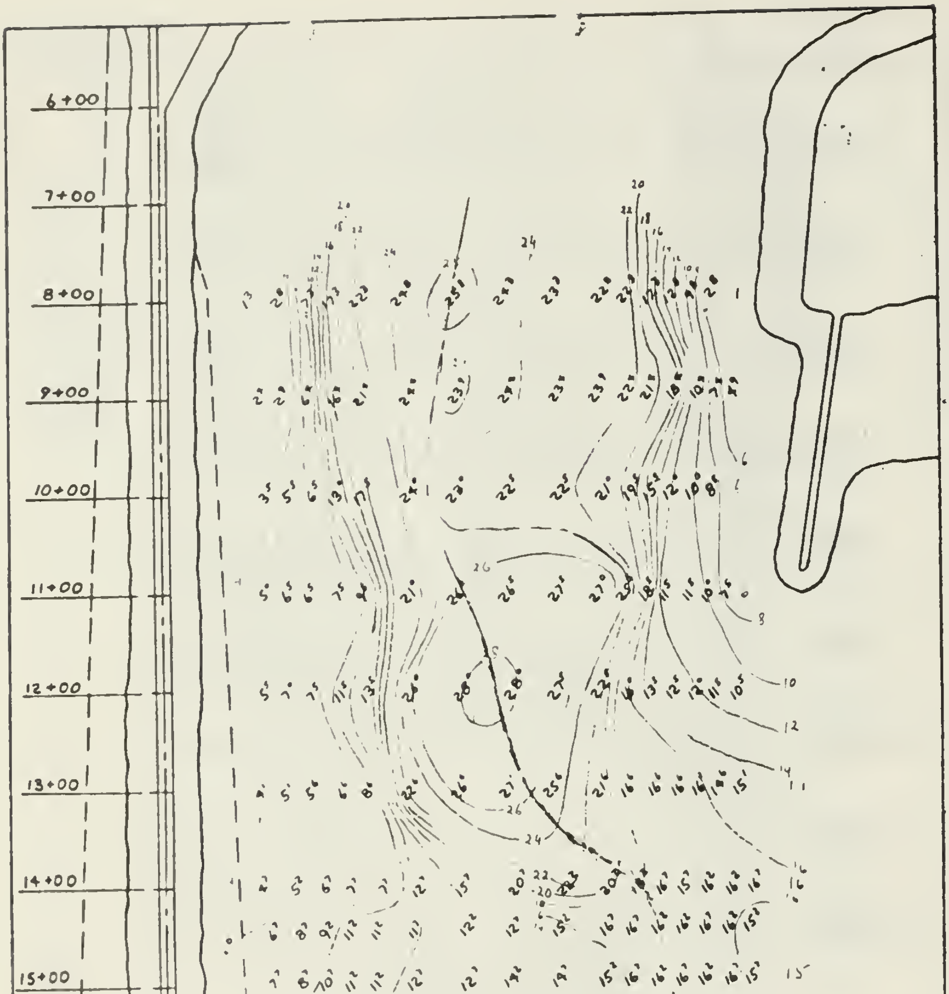
VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
DATE: 26 APRIL '67
DATUM IS M.L.L.W.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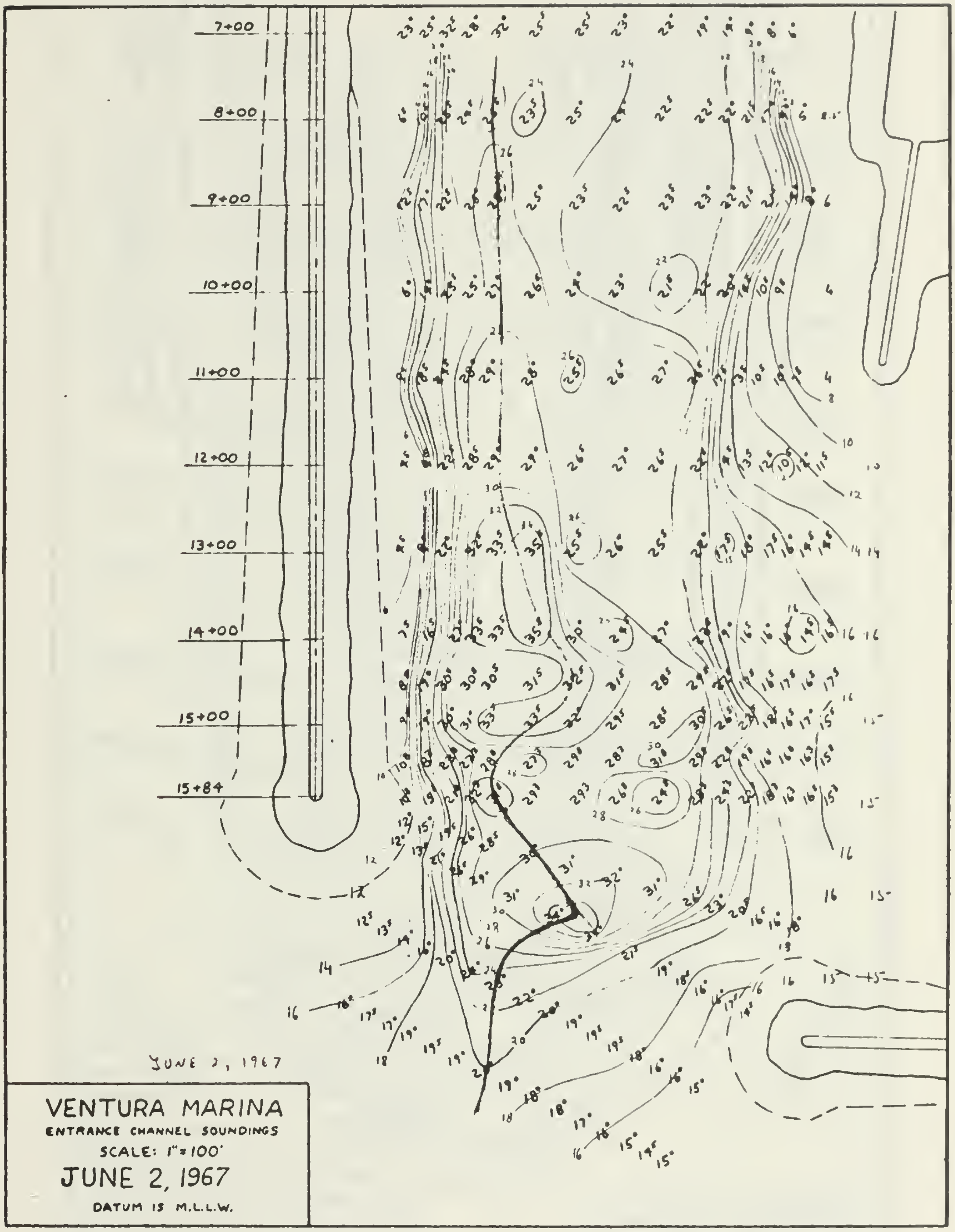
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
DATE: 9 MAY 67
DATUM IS M.L.L.W.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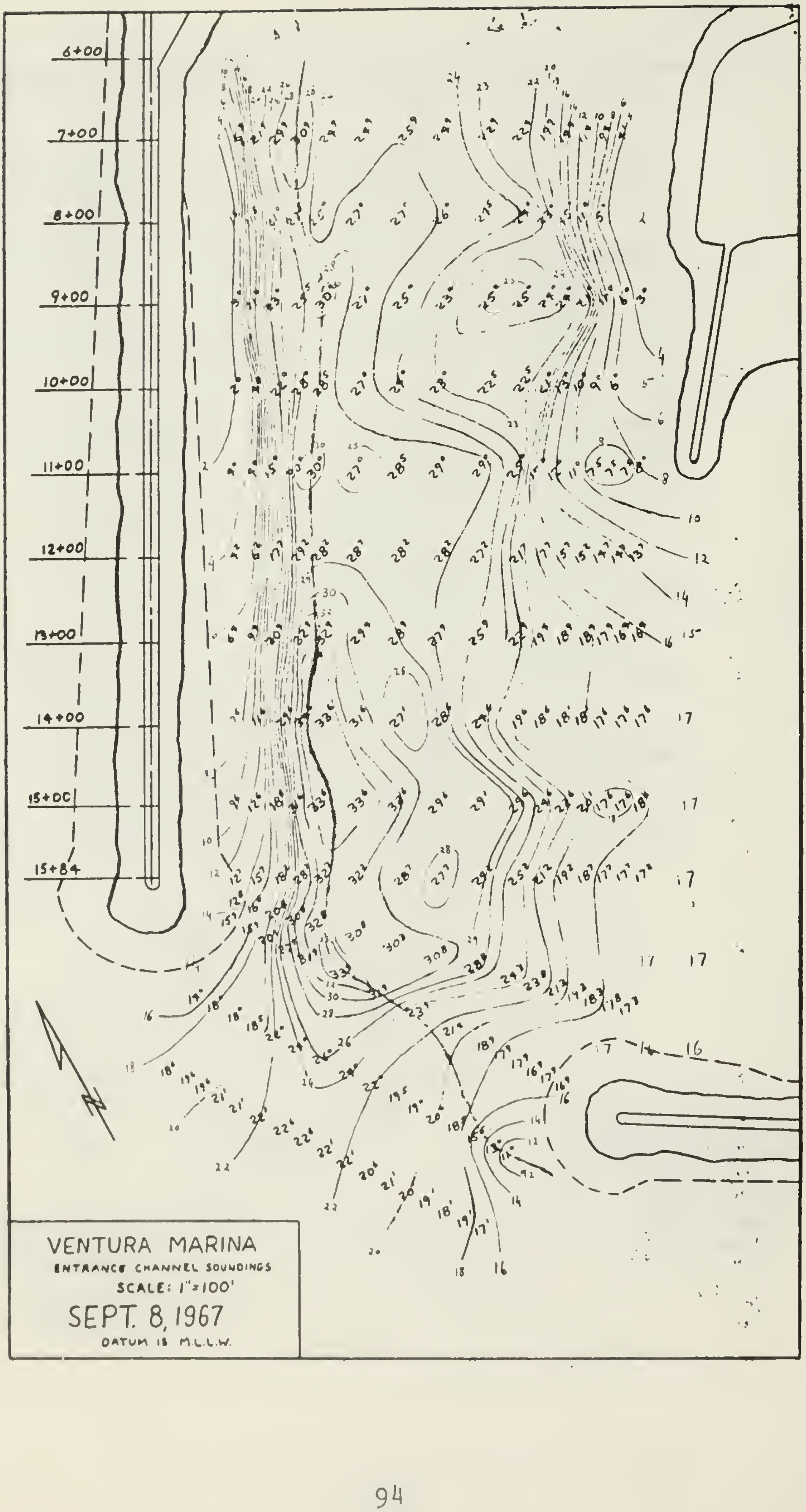
JUNE 2, 1967
VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1"=100'
JUNE 2, 1967
DATUM IS M.L.L.W.


VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1"=100'
SEPT. 8, 1967
DATUM IS M.L.L.W.
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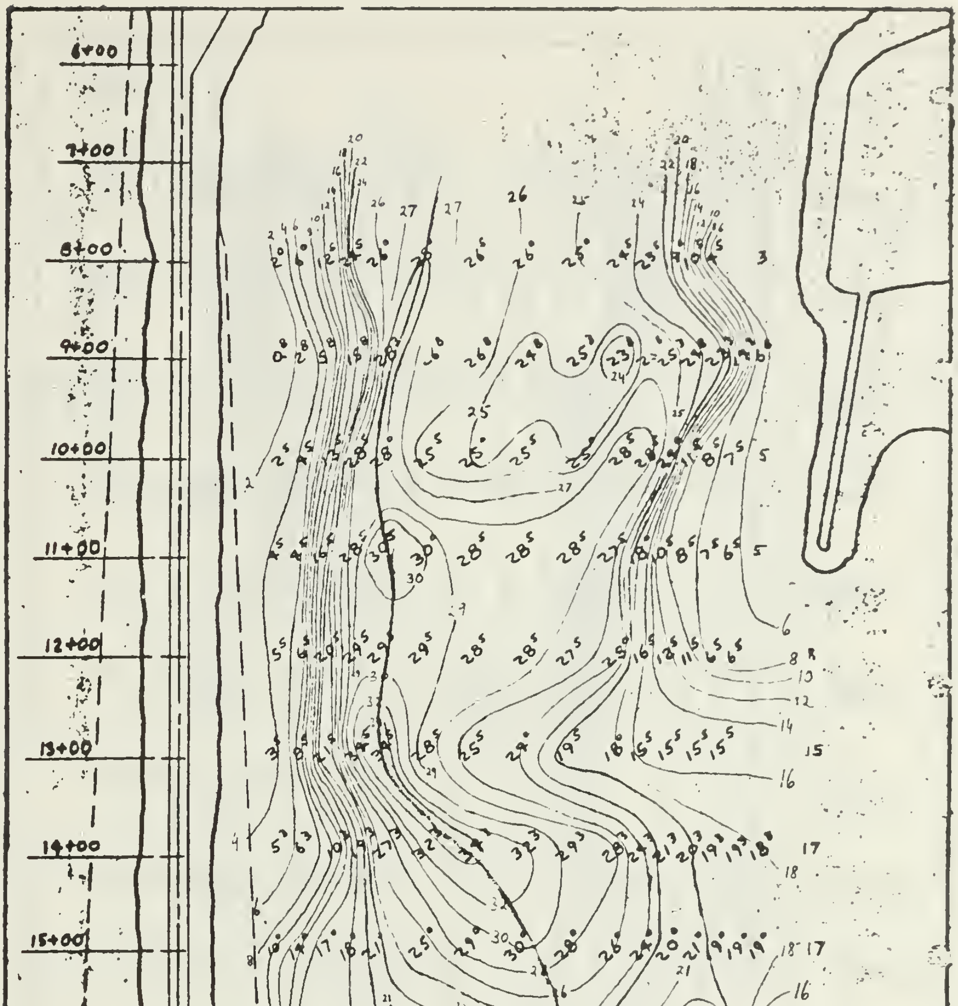
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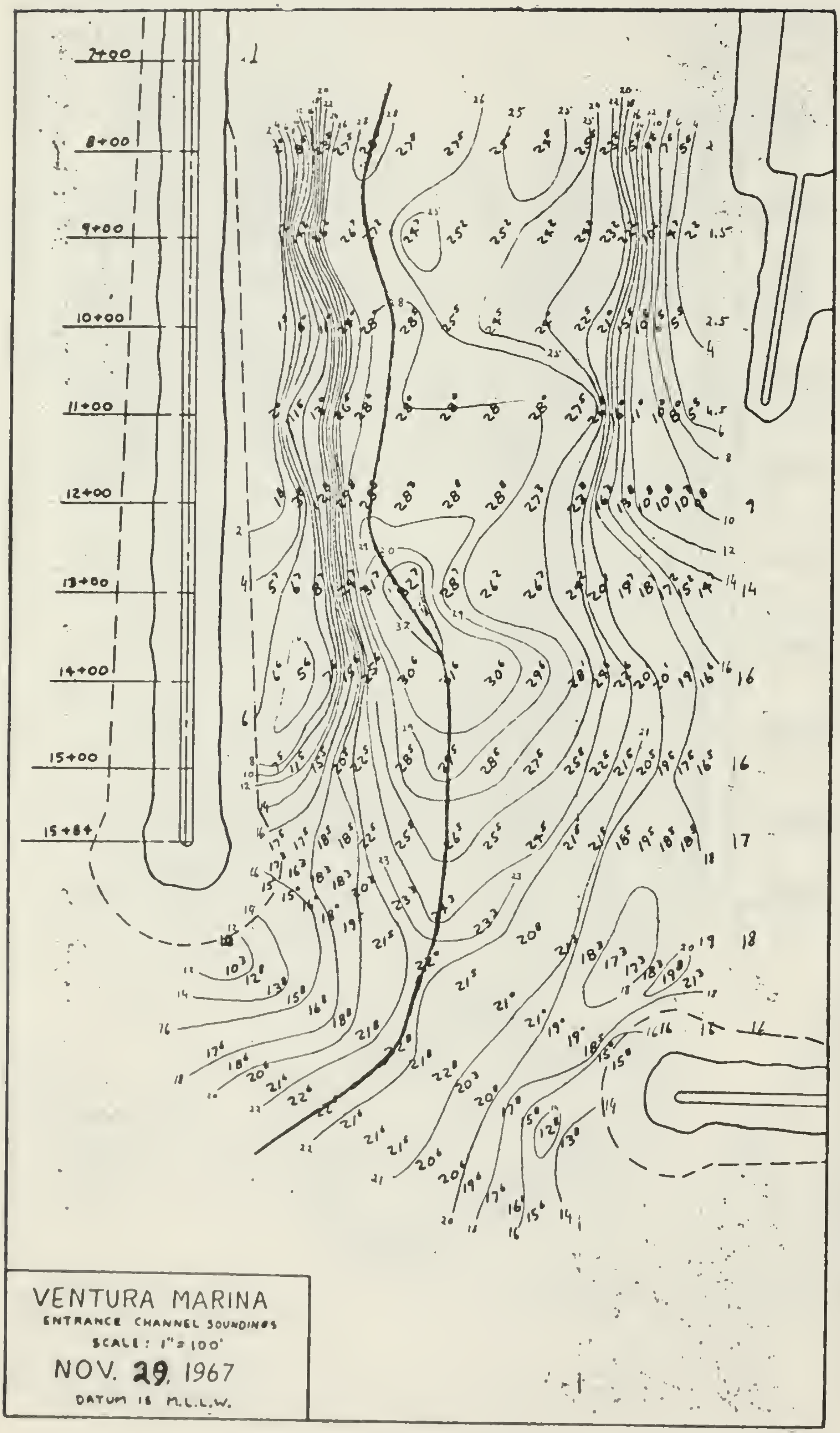
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
OCT. 17, 1967
DATUM IS M.L.L.W.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VENTURA MARINA
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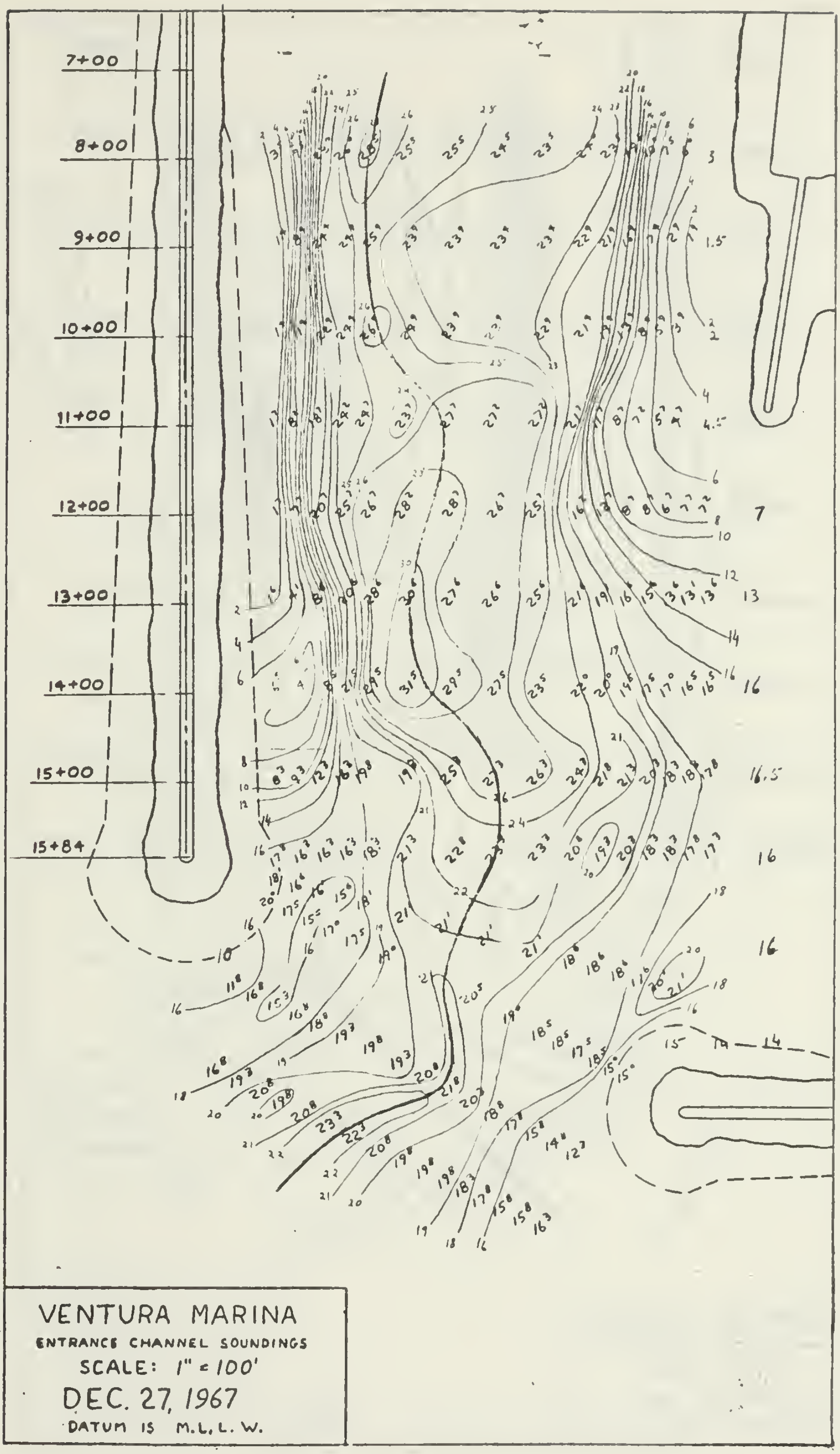
SCALE: 1"=100'
NOV. 29, 1967
DATUM IS M.L.L.W.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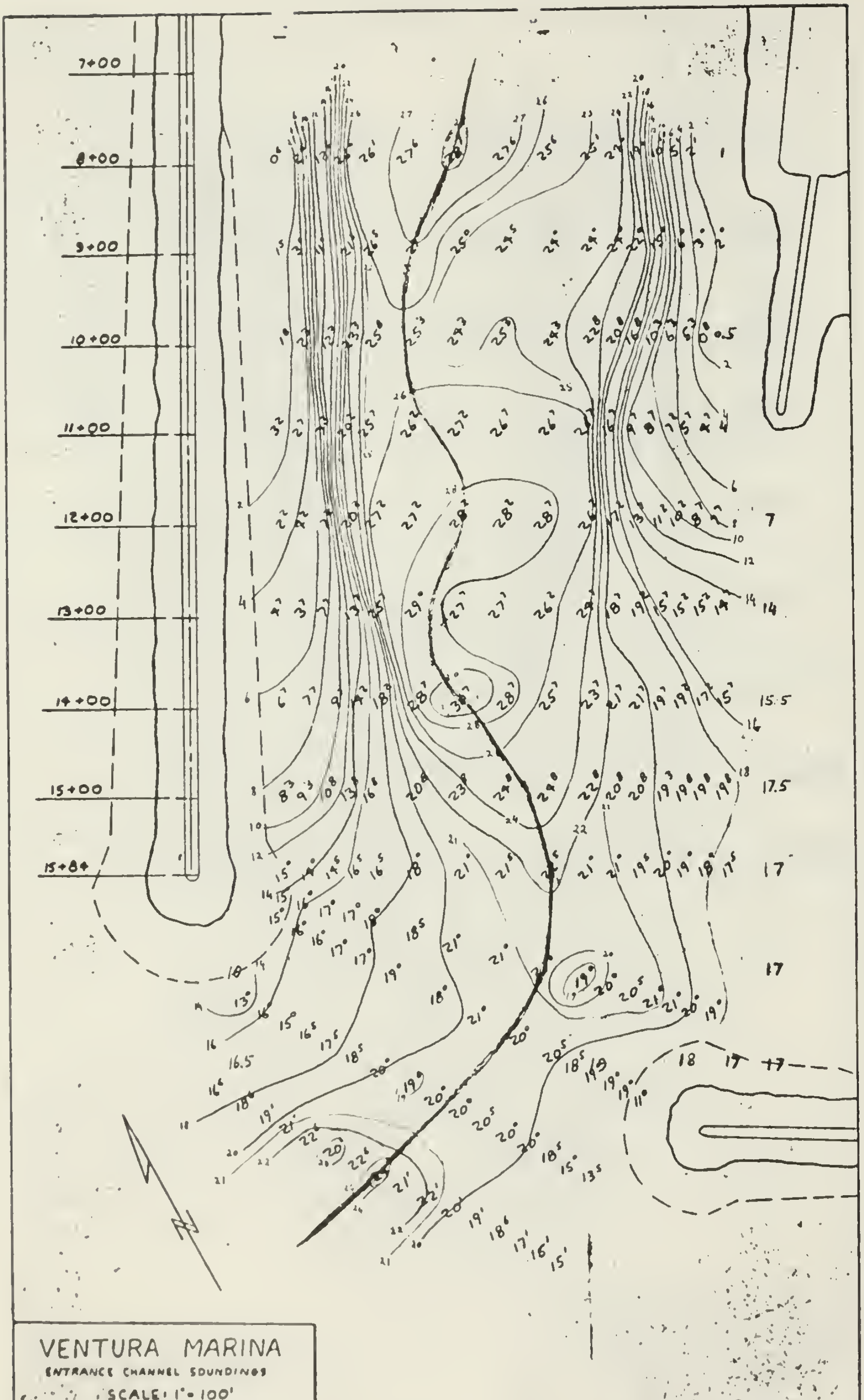
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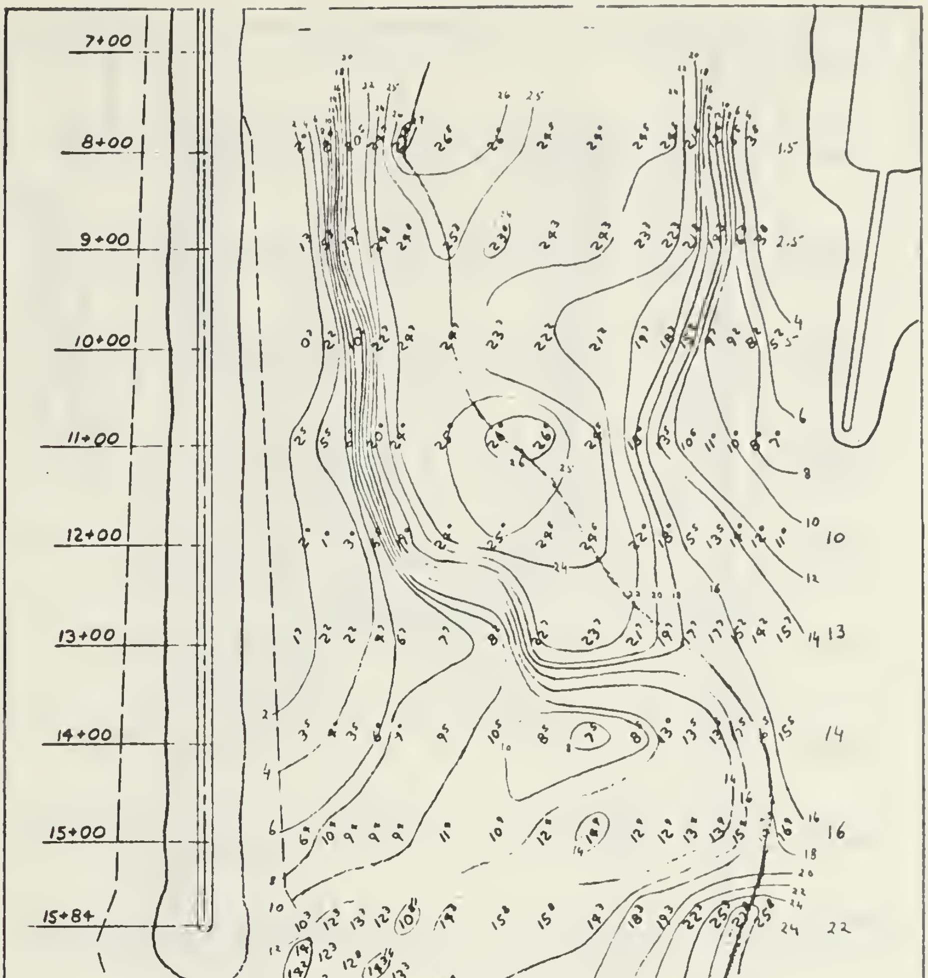
SCALE: 1" = 100'
JAN. 31, 1968
DATUM IS M.L.L.W.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VENTURA MARINA
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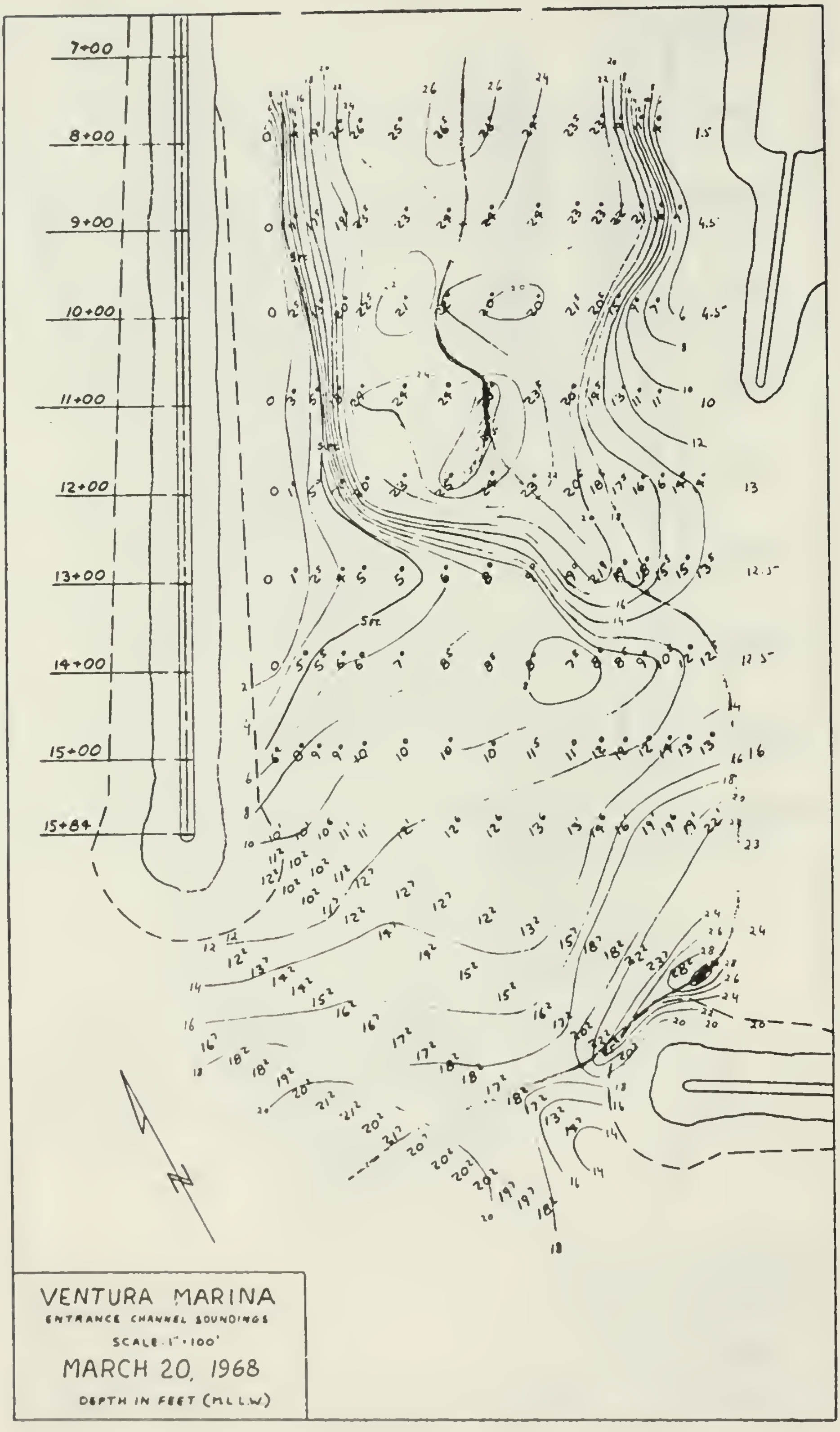
SCALE: 1" = 100'
MARCH 11, 1968
DATUM IS M.L.L.W.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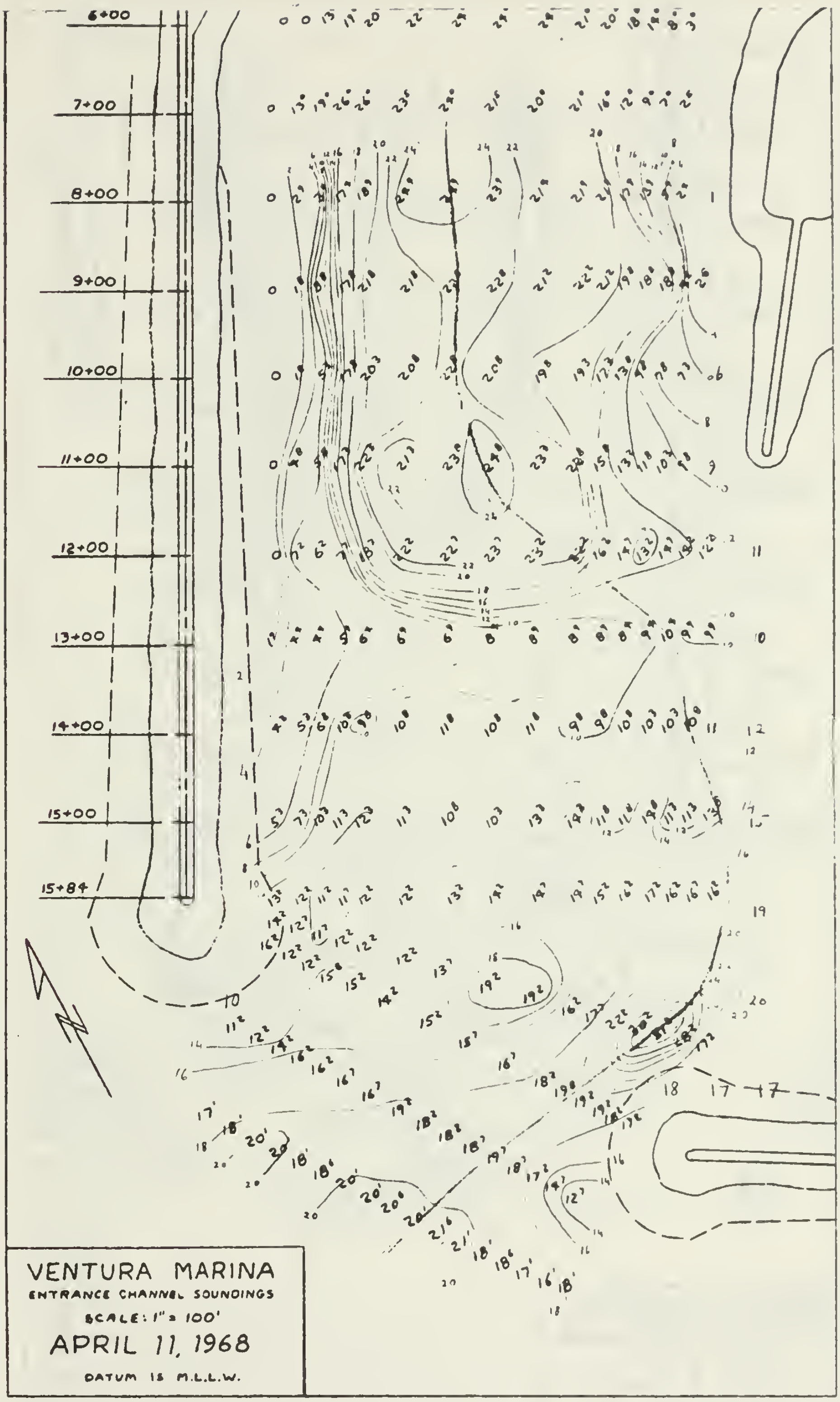
SCALE 1" = 100'
MARCH 20, 1968
DEPTH IN FEET (MLLW)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ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
APRIL 11, 1968
DATUM IS M.L.L.W.
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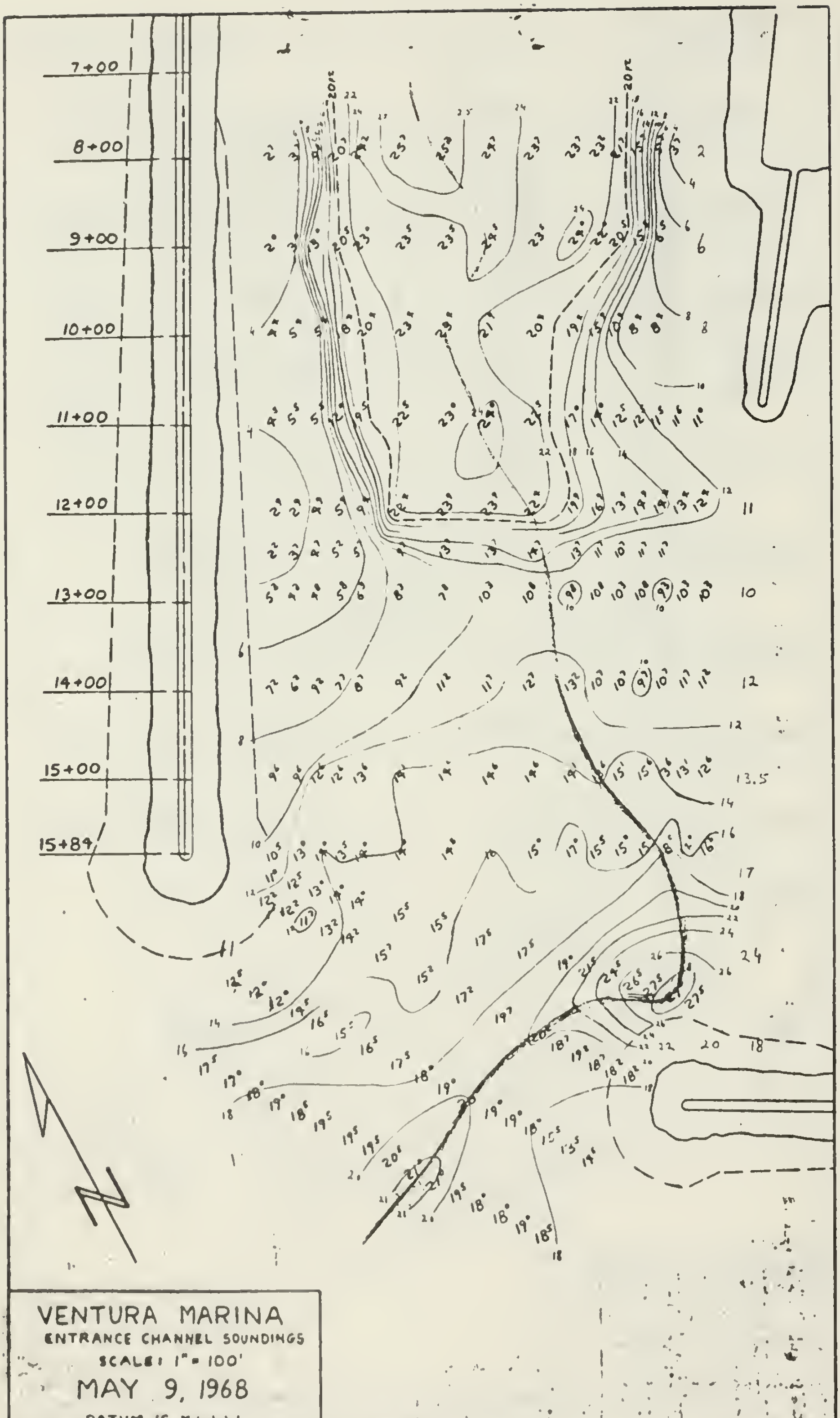
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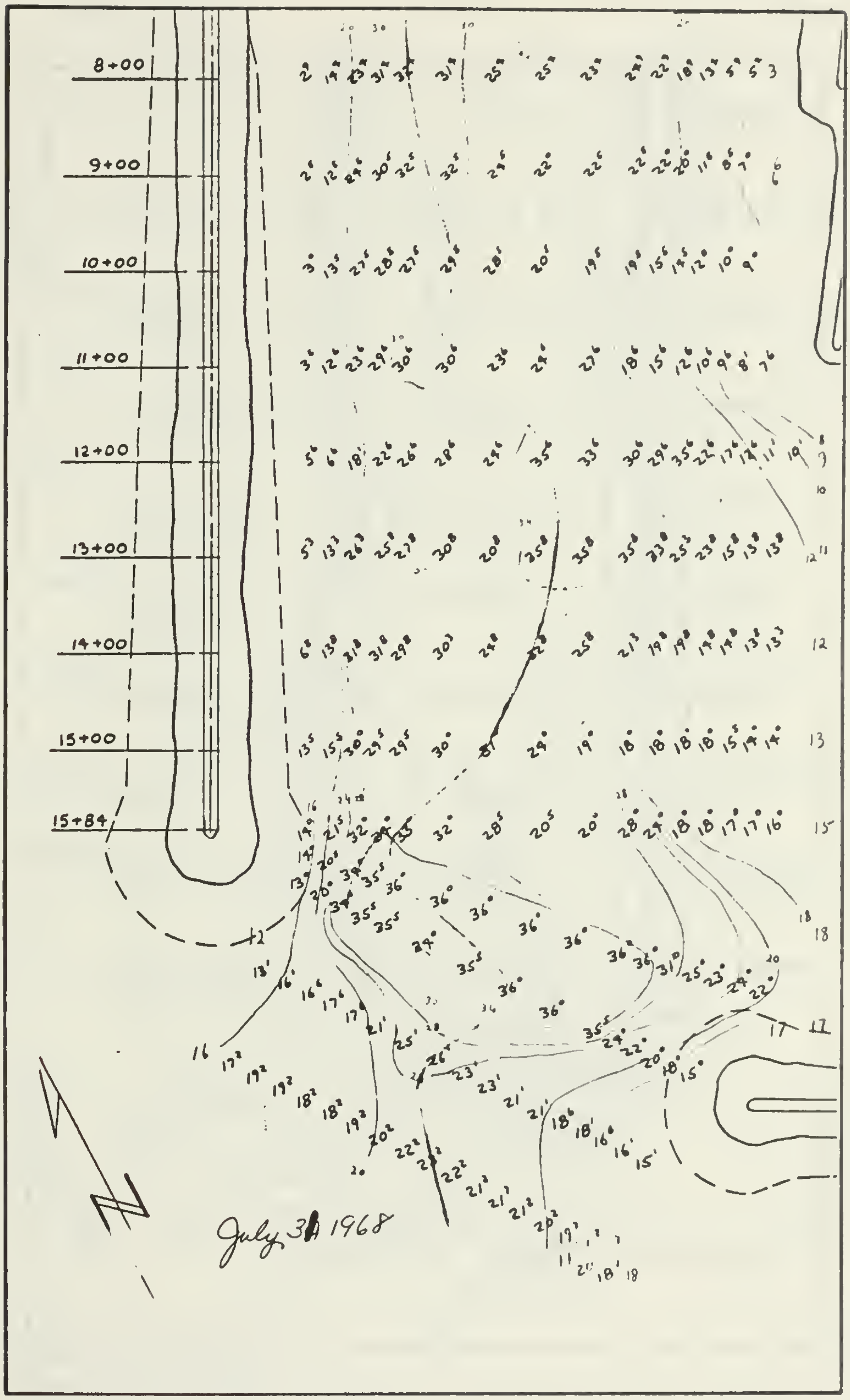
VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
MAY 9, 1968
DATUM IS M.L.L.W.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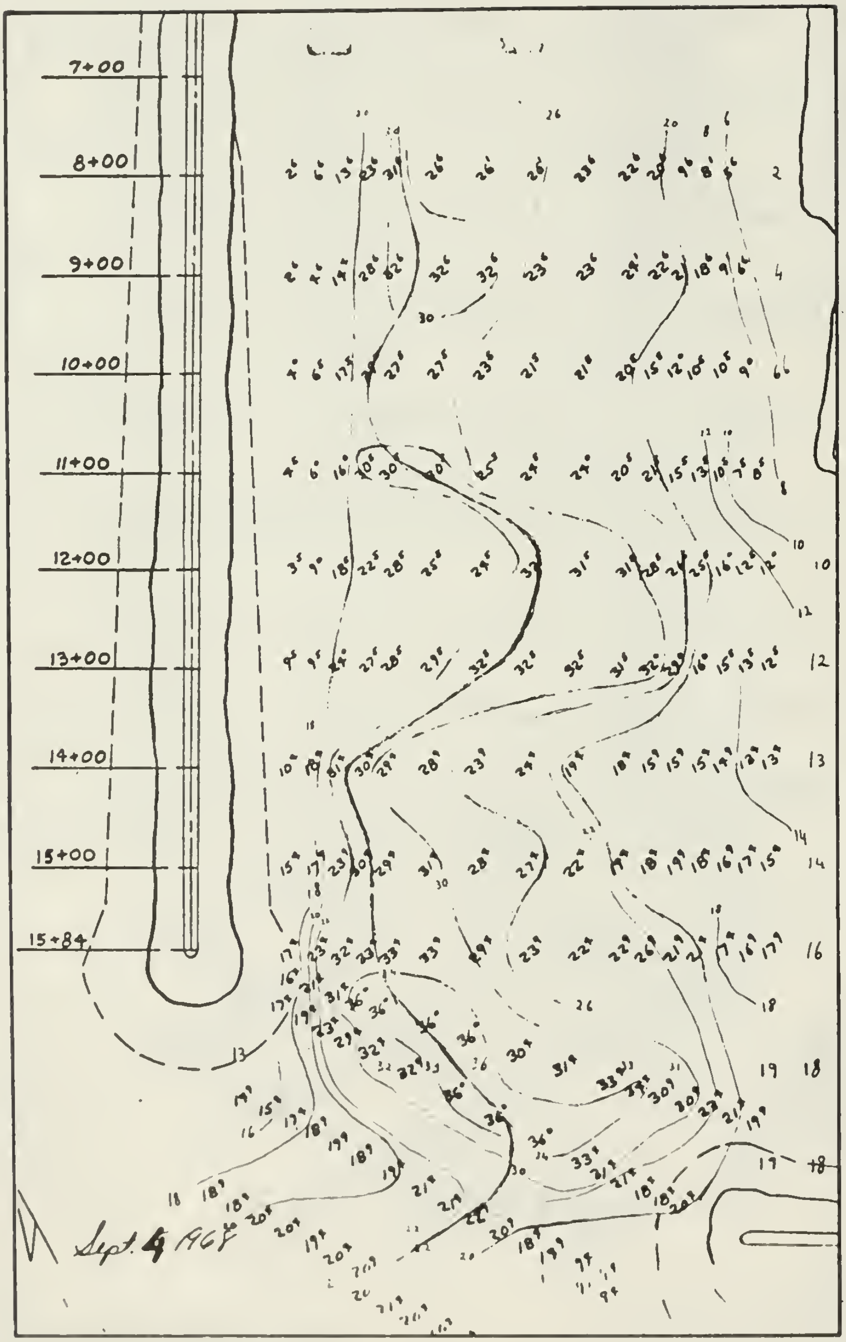
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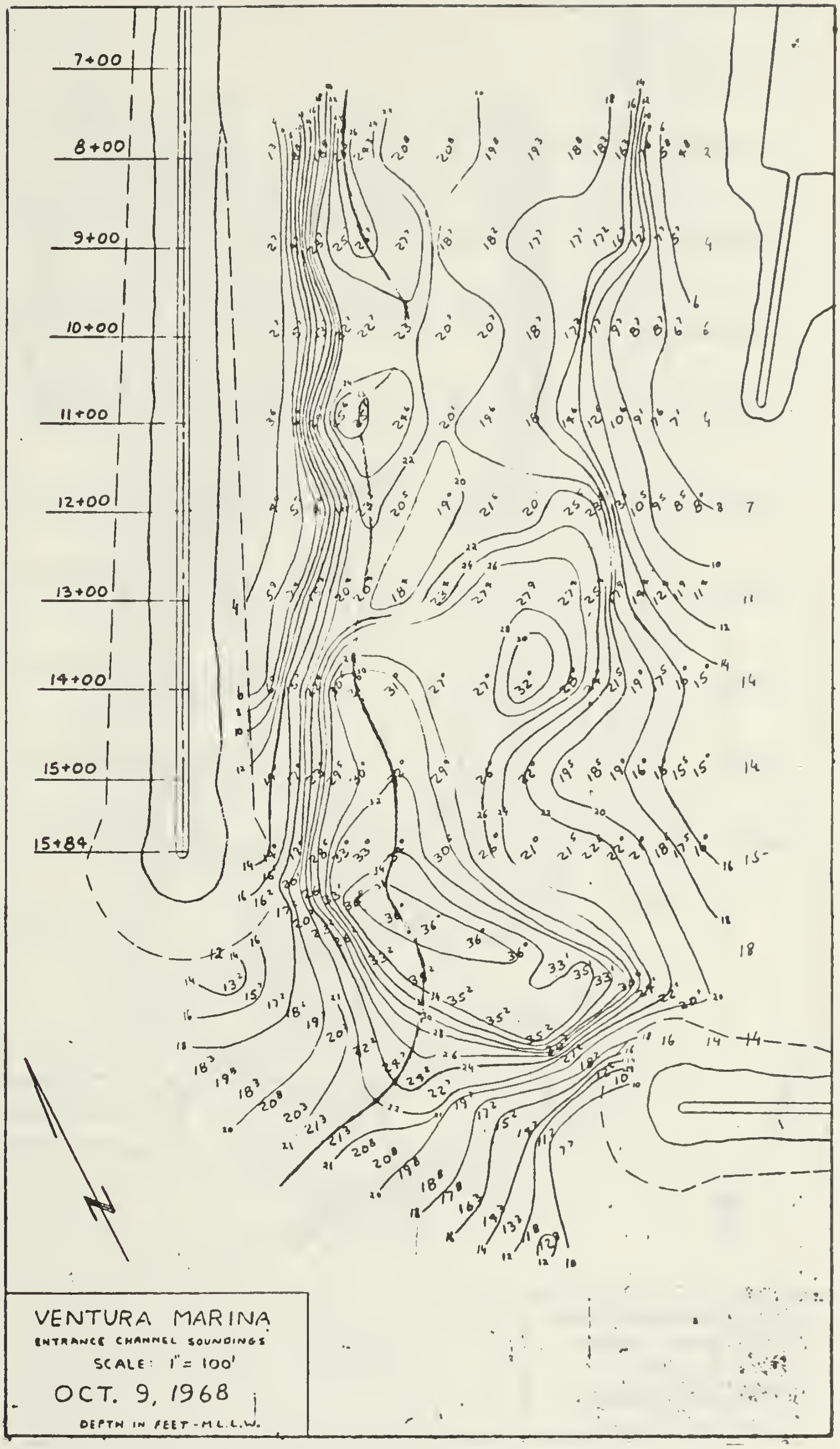
Sept. 4 1967



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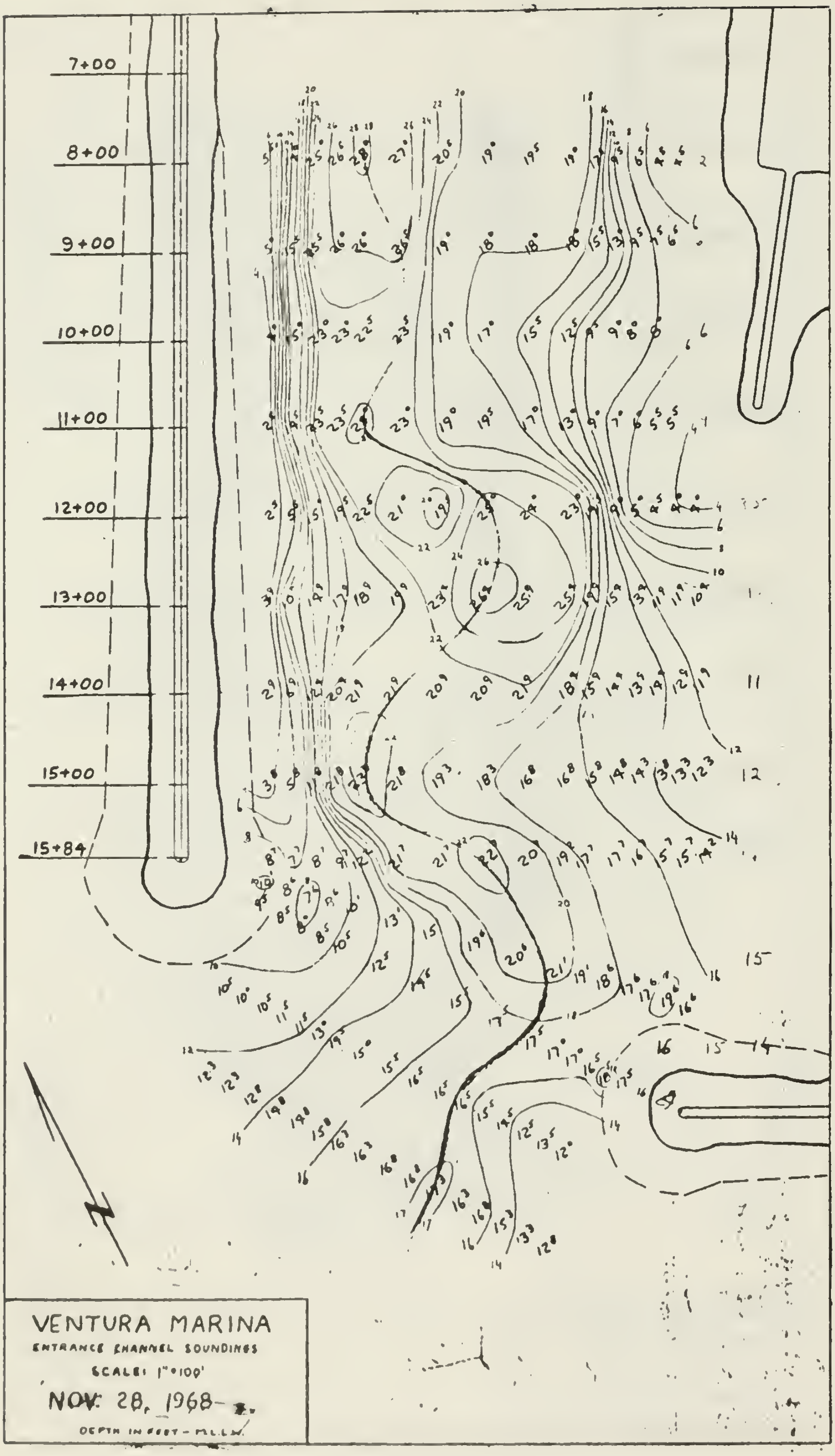
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1" = 100'
OCT. 9, 1968
DEPTH IN FEET - M.L.L.W.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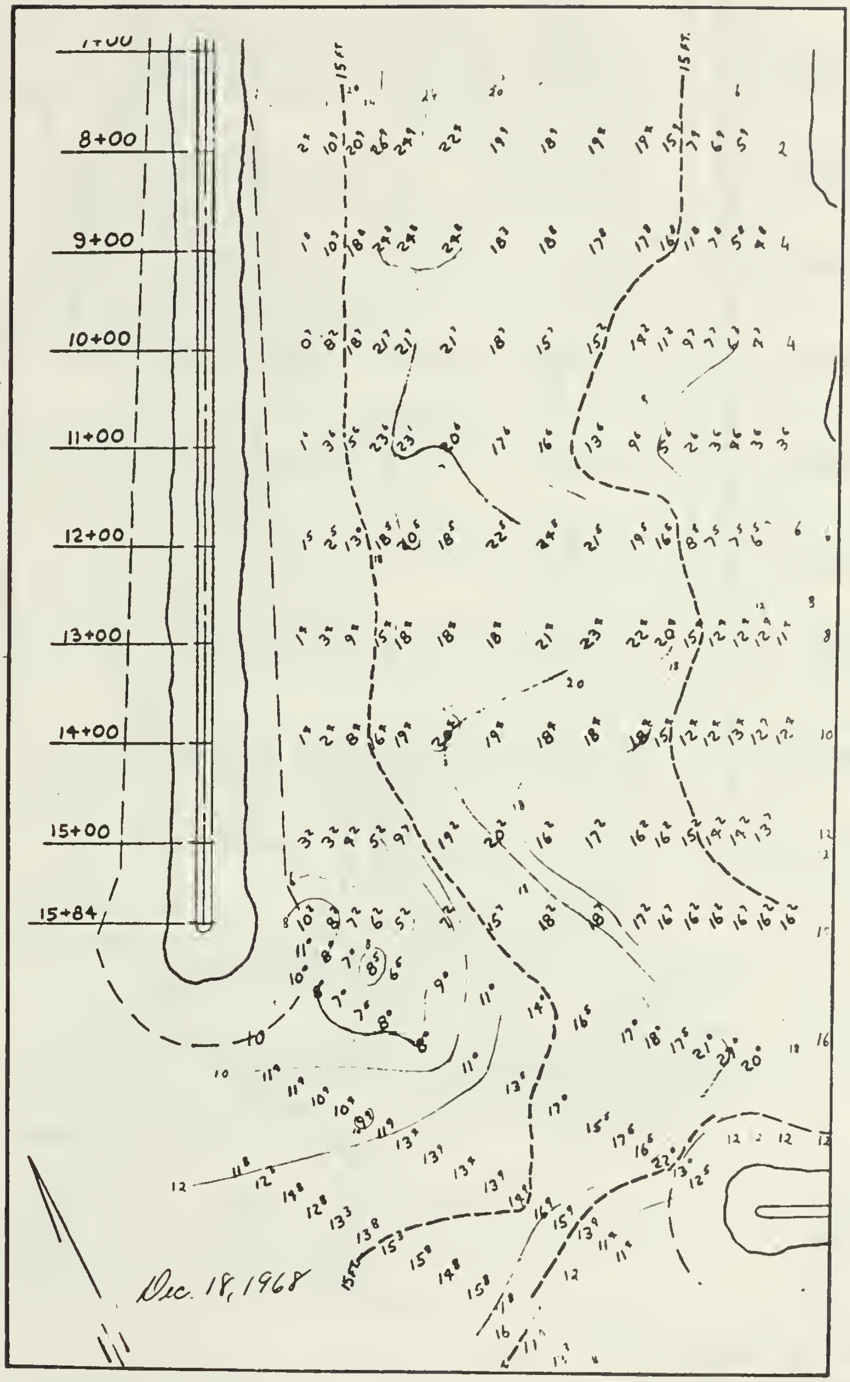
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1"=100'
NOV. 28, 1968
DEPTH IN FEET – M.L.L.W.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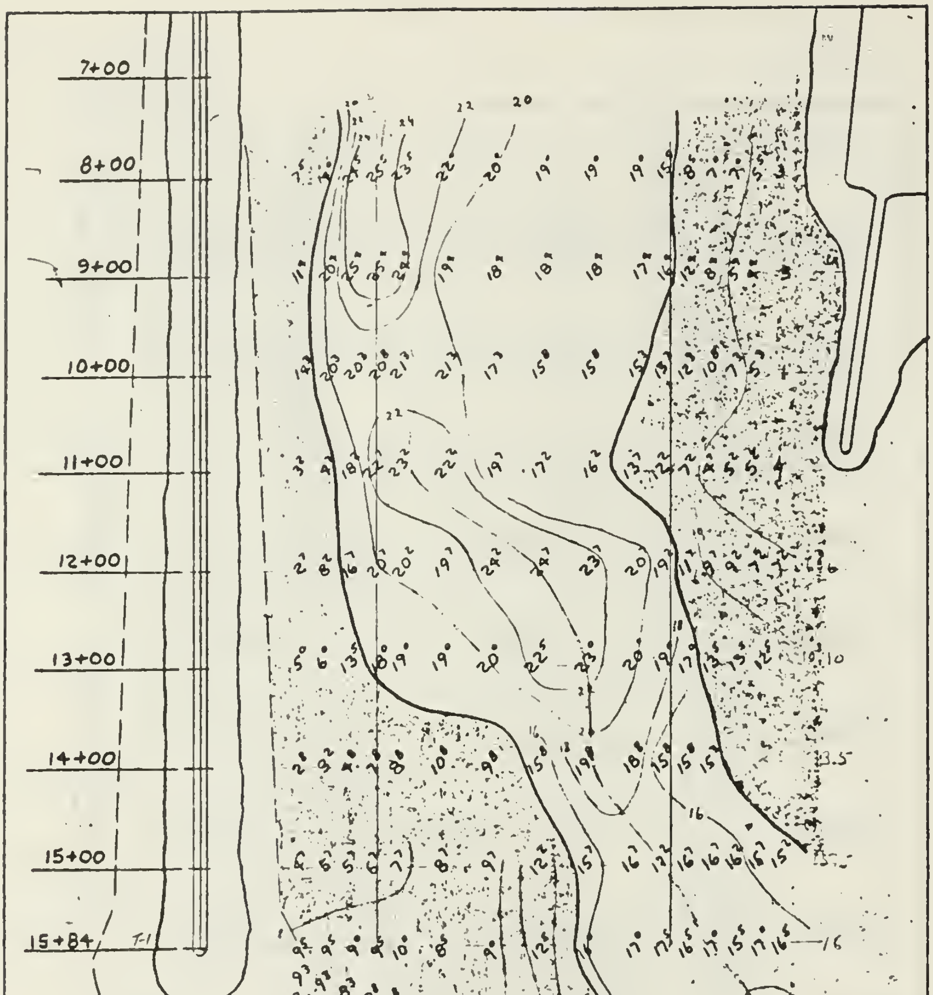
Dec. 18, 1968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VENTURA MARINA
ENTRANCE CHANNEL SOUNDINGS
SCALE: 1"=100'
JAN. 16, 1969
DEPTH IN FEET - M.L.L.W.

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